A COMPARISON OF DENTAL AND SKELETAL CHANGES BETWEEN RAPID PALATAL EXPANSION AND NICKEL TITANIUM PALATAL EXPANSION

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CHAPTER I

INTRODUCTION

A. BACKGROUND

Palatal expansion used to correct maxillomandibular transverse discrepancies occurs through a combination of skeletal (orthopedic) expansion, which involves separating the maxilla at the midpalatal suture, and dental (orthodontic) expansion, which results from buccal tipping of the maxillary posterior teeth. The proportion of skeletal and dental movement is dependent on the rate of expansion (rapid or slow) and the age of the patient during treatment.[1-4] The goal of palatal expansion is to maximize the skeletal movement and to minimize the dental movement,[5,6] while allowing for physiological adjustment of the suture during separation.[7,8]

Expansion appliances can be classified as rapid or slow expanders. Rapid maxillary expansion produces large forces at the sutural site over a short period of time.[6] These high magnitude forces maximize skeletal separation of midpalatal suture by overwhelming the suture before any dental movement or physiological sutural adjustment can occur.[2,9,10] Hence, advocates of rapid maxillary expansion such as Haas[5,9] believe that it results in minimum dental movement (tipping) and maximum skeletal movement.

The disadvantage of using rapid palatal expanders include discomfort due to traumatic separation of the midpalatal suture,[11] inability to correct rotated molars, require patient or parent cooperation in activation of the appliance, and labor-intensive laboratory procedures in fabrication of the appliance.

Advocates of slow expansion appliances, such as the quad-helix and W-arch, have questioned the need of such large rapid forces for sutural separation.[6,12] It is believed that slow expansion allows for more physiologic adjustment to sutural separation.[7,8] This in turn, produces greater stability and less relapse potential while still producing skeletal separation of the maxilla that is comparable to rapid expansion techniques.[3]

In an attempt to design an appliance that is capable of producing physiologic skeletal expansion, Arndt,[13] in 1993, developed a tandem-loop nickel titanium, temperature-activated palatal expander with the ability to produce light, continuous pressure on the midpalatal suture. This appliance is also capable of correcting molar rotation and requires little patient cooperation or laboratory work.

The purpose of this study is to evaluate and compare the maxillary dental and skeletal changes of a nickel titanium palatal expansion appliance[13] to a rapid palatal expansion appliance. Specifically, the amount of midpalatal suture separation, maxillary alveolar tipping, maxillary first molar tipping, maxillary first molar rotation, and palatal depth changes in response to treatment will be measured.

B. STATEMENT OF THE PROBLEM

The nickel titanium, temperature-activated palatal expander is claimed to produce a light, continuous force which is capable of expanding the maxilla and correcting molar rotations. The skeletal and dental effects of the nickel titanium palatal expander on the maxilla have not been reported in the literature.

C. SIGNIFICANCE OF THE STUDY

The results of this study will provide information on the skeletal and dental effects produced by a nickel titanium, temperature-activated palatal expander. This information will aid clinicians in selecting the appropriate appliance for maxillary expansion in children.

D. HYPOTHESIS

1. There is a significant increase in maxillary intermolar width, palatal width, maxillary alveolar tipping, palatal depth, maxillary molar tipping and maxillary molar rotation following treatment in both the nickel titanium palatal expansion group and the rapid palatal expansion group.

2. There is a significant correlation between age and changes in maxillary intermolar width, palatal width, alveolar tipping and molar tipping in both the nickel titanium palatal expansion group and the rapid palatal expansion group.

3. There is a significant correlation between intermolar width increase and increases in palatal width, alveolar tipping and molar tipping in both the nickel titanium palatal expansion group and the rapid palatal expansion group.

4. There is a significant difference in intermolar width change, palatal width change, palatal depth change, alveolar tipping, molar rotation and molar tipping between rapid palatal expansion and nickel titanium palatal expansion.

E. OPERATIONAL DEFINITIONS

1. Palatal or maxillary expansion - A transverse widening of the maxilla that occurs through a combination of separation of the midpalatal suture of the maxilla and buccal tipping the posterior teeth.

2. Expansion appliance - The device that is used to apply the force that is necessary to expand or widen the maxilla.

3. Orthopedic or skeletal palatal expansion - The widening of maxilla due to skeletal responses such as a separation of the midpalatal suture.

4. Orthodontic or dental palatal expansion - The widenening of the maxilla due to dental responses such as buccal tipping of the posterior teeth.

5. Rapid palatal expansion - Expansion of maxilla accomplished through heavy forces that are capable of separating the midpalatal suture at the rate of 0.2 to 0.5 mm per day.

6. Slow palatal expansion - Expansion of maxilla accomplished through light forces that are capable of separating the midpalatal suture at the rate. of 0.5 to 1.0 mm per week.

7. Symmetrograph (pantograph) - An instrument for copying a figure to any desired scale.

8. Anterior nasal spine (ANS) - The most anterior point on the maxilla.

9. Posterior nasal spine (PNS) - The most posterior point on the maxilla.

10. Point A - The deepest point on the curved outline of the maxilla between ANS and the incisors.

11. Point B. - The deepest point on the curved outline of the anterior part of the mandible.

12. Sella (S) - The center of the pituitary fossa.

13. Nasion (N) - The most anterior point along the frontonasal suture.

14. Sella-nasion-point A angle (SNA) - The angle formed by connecting sella to nasion, and nasion to point A.

15. Sella-nasion-point B angle (SNB) - The angle formed by connecting sella to nasion, and nasion to point B.

16. Point A-nasion-point B angle (ANB) - The angle formed by connecting point A to nasion, and nasion to point B.

17. Pogonion - The most prominent point on the bony chin.

18. Angle of convexity - The angle formed by connecting nasion to point A, and point A to pogonion minus 180 degrees.

19. Facial plane - A line connecting nasion and point B.

20. Mandibular plane - A line parallel to the inferior border of the mandible.

21. Palatal plane - A line connecting ANS with PNS.

22. Prosthion - The intersection of the alveolar process and the maxillary central incisors.

F. ASSUMPTIONS

It is assumed that all diagnostic materials utilized such as alginate impressions, study models, and occlusal radiographs are taken and prepared in a consistent fashion according to professional standards and that the effect of errors, such as impression

distortion, and dental cast trimming and polishing, will be the same for both groups. It is also assumed that because the nickel titanium expansion appliance is standardized to 3-4 mm greater than the intermolar width, that enough force is produced to allow for midpalatal suture separation. It is also assumed that all rapid expansion appliances whether banded or bonded produce comparable amounts of lateral expansion to each other and that any differences are insignificant. Also, since multiple operators are involved in the placement of the expansion appliances, it is assumed that the appliances are inserted and activated in a consistent manner.

G. LIMITATIONS

In accordance with ethical and professional standards on the use of slow expansion appliances, the patients used in this study will be limited in dental development to the primary to early permanent dentition. Improper dental hygiene or care of the expansion appliances could lead to gingival hyperplasia which could have an effect on the outcome of pre and posttreatment dental cast measurements. Bony remodeling during slow expansion may mask the ability to distinguish sutural separation on occlusal radiographs. Also, the accuracy of adaptation of the nickel titanium expander to the lingual surfaces of the maxillary primary molars and canines could affect the amount of lateral expansion.

H. DELIMITATIONS

All patients used in this study will require palatal expansion as part of their orthodontic treatment and range from the primary dentition to the early permanent

dentition with no previous history of orthodontic treatment. Patients with cleft palate who require palatal expansion will be excluded from the study. Also, the patients will not have any exsisting medical condition that could affect their normal growth and development.

CHAPTER II

REVIEW OF THE LITERATURE

A. POSTERIOR CROSSBITES

Maxillary expansion is used to correct transverse discrepancies between the maxilla and the mandible. This discrepancy is clinically manifested in the form of a posterior crossbite. The incidence of posterior crossbites in children from study to study varies from 1% to 23%.[14,15] This figure also varies among different populations. The incidence of posterior crossbites in American Caucasion children was found to be approximately 7%.[16,17] The occurrence in Scandanavian children was reported to be higher by Kisling(13.2%)[18] and Kurol(23. 3%).[15] Compared to caucasian children, African and African American children reportedly have a lower incidence of posterior crossbites. Infante[17] found a prevelance of 2.1% in an African American population while Kerosuo[14] reported that 1% of his African sample had a posterior crossbite.

Zhu[19] reported that the etiology of crossbites is multifactorial and could be related to genetic, congenital, environmental, functional, or habitual factors. Along with congenital and genetic factors, specific studies have reported that crossbites can develop because of abnormal swallowing patterns, mouthbreathing, or because of prolonged digit or pacifier sucking.[20,21]

A maxillomandibular transverse discrepency can result in either a unilateral or bilateral posterior crossbite. If the discrepency is mild, a unilateral posterior crossbite can develop and is usually compensated for by a lateral shift of the mandible in order to maintain maximum intercuspation with the maxillary teeth. Clinically, a unilateral posterior crossbite is evidenced by a midline shift of the mandible to one side or the other

with a crossbite occurring on only one side while the other side occludes normally. On the other hand, if the maxillomandibular transverse discrepancy is severe enough, a bilateral posterior crossbite will result. A bilateral posterior crossbite will usually manifest with the maxillary and mandibular dental midlines being coincident and a crossbite of both right and left posterior dental segments.

Whether the cause of the posterior crossbite is due to a constricted maxilla or a disproportionately wide mandible, transverse problems in children are often treated by expansion of the maxilla. This expansion or widening of the maxilla is accomplished by a combination of orthopedic (skeletal) expansion and orthodontic (dental) expansion. Orthopedic expansion involves separating the right and left maxillary halves at the midpalatal suture while orthodontic expansion results from buccal tipping of the maxillary posterior teeth.[1-3,7,9,22-25]

B. HISTORICAL PERSPECTIVE OF MAXILLARY EXPANSION

One of the first descriptions of an attempt to expand the maxilla was by Angell[26] in 1860. He described an appliance that included a palatal jackscrew attached to the premolars which the patient turned twice daily. After two weeks of activation, Angell[26] reported a widening of the maxilla and concluded that skeletal seperation of the maxilla had occured as evidenced by the development of a diastema between the patient's maxillary central incisors.

During the latter part of the nineteenth century and early twentieth century, palatal expansion was used very sporadically in the United States. This was due to the popular concept of functional development. This concept theorized that maxillary expansion

could be accomplished by conventional orthodontic movement and once the teeth were functioning in their proper position, the bone would grow to accommodate the new position of the dentition. This theory of expansion remained popular until 1938 when Brodie[27] reported that the functional concept of development produced changes only in the supporting alveolus and that the maxillary bone did not expand to adapt to teeth as once thought.

During the time that the functional concept of development was popular in America, Europeans continually used palatal expansion as an acceptable method of treatment. It wasn't until the early 1960's when Korkhaus[28] reintroduced palatal expansion in America and once back in America, palatal expansion was further popularized by the studies of Haas[5,29] who reported the ease and extent to which painless separation of the maxilla can occur.

C. NORMAL TRANSVERSE GROWTH OF THE MAXILLA

Bishara[30] evaluated normal arch width changes from 6 weeks to 45 years of age by analyzing the dental casts of a sample of 61 infants at 6 weeks, 1 year, and 2 years of age and a sample of 30 subjects at 3, 5, 8, 13, 26, and 45 years of age. The author found significant increases in maxillary and mandibular intermolar and intercanine widths in both males and females from 6 weeks to 2 years of age with the average increase in intercanine width from birth to 2 years being equal to or only 1.0 mm less than the total increase from 3-45 years of age. From 3-13 years, there was also significant increase in maxillary and mandibular intermolar and intercanine widths in males and females. However, from 13-45 years, both maxillary and mandibular intermolar and intercanine

widths showed slight decreases. The findings from this study (Tables 1 and 2) suggest establishment of arch width dimensions during the mixed dentition period (8 years of age), with a slight increase until the eruption of the permanent dentition, followed by a progressive, but minimal, decrease until middle age.

Table 1. Maxillary and Mandibular Intermolar Width Increases (mm) from 6 Weeks to 45 Years of Age (Bishara[30])

	Maxillary intermolar increase				Mandibular intermolar increase			
	Male		Female		Male		Female	
Age	x	ρ	x	ρ	x	ρ	x	ρ
6 weeks-1 yr	2.7	0.0001	2.2	0.0001	2.5	0.0001	1.9	0.0001
1 yr-2 yrs	2.6	0.0001	1.7	0.0066	0.1	0.8269	1.5	0.1949
3 yrs-5 yrs	2.6	0.0001	1.5	0.0063	2.1	0.0001	-0.4	0.6900
5 yrs-8 yrs	7.5	0.0001	7.3	0.0001	7.7	0.0001	7.7	0.0001
8 yrs-13 yrs	2.4	0.0001	2.0	0.0001	1.3	0.0001	0.9	0.0098
13 yrs-26 yrs	0.2	0.8840	-1.8	0.0250	0.1	0.9910	-1.5	0.7960
26 yrs-45 yrs	-0.2	0.4930	0.1	0.4090	-0.3	0.4025	0.0	0.7004

x = mean increase in mm; ρ = level of significance

Table 2. Maxillary and Mandibular Intercanine Width Increases (mm) from 6 Weeks to 45 Years of Age (Bishara[30])

	Maxillary intercanine increase				Mandibular intercanine increase			
	Male		Female		Male		Female	
Age	x	ρ	x	ρ	x	ρ	x	ρ
6 weeks-1 yr	2.3	0.0001	2.0	0.0001	2.1	0.0001	1.7	0.0001
1 yr-2 yrs	1.9	0.0001	2.0	0.0001	0.2	0.5100	0.5	1.0000
3 yrs-5 yrs	1.5	0.0079	1.0	0.0197	1.3	0.0010	0.8	0.0115
5 yrs-8 yrs	2.2	0.0001	2.3	0.0001	2.1	0.0001	2.1	0.0001
8 yrs-13 yrs	2.6	0.0001	2.2	0.0001	0.2	0.4000	1.0	0.0165
13 yrs-26 yrs	-0.9	0.1900	-0.8	0.1780	-0.5	0.3130	-1.0	0.0674
26 yrs-45 yrs	-0.3	0.1180	-0.4	0.0190	-0.4	0.0029	-0.6	0.0002

x = mean increase in mm; ρ = level of significance

Sillman[31] evaluated dental arch changes in a mixed sample of 65 subjects from birth to 25 years of age. From birth to 2 years of age, he observed significant increases ($p<0.05$) in intercanine widths of 5 mm in the maxilla and 3.5 mm in the mandible. From 2 years on, there was a continual increase in intercanine width in the maxilla until age 13 and in the mandible until age 12. After which, the canine width remained stable. From the complete eruption of the deciduous dentition (mean age 3.27 years) to the eruption of the second molars (mean age 13.64 years), there was a significant increase in maxillary intermolar width of about 0.5 mm per year and in mandibular intermolar width of 0.2 mm per year. After age 14, maxillary and mandibular intermolar widths showed no significant evidence of any changes.

In a longitudinal study, Knott[32] quantified dental arch width changes between maxillary and mandibular lateral incisors, canines, and deciduous second molars/permanent second premolars from the deciduous dentition (mean age of 5.4 years) through the young adult dentition (mean age of 25.9 years). Intercanine width showed significant increases (Table 3) in both the maxilla and mandible from the deciduous dentition to mixed dentition (mean age of 9.4 years). From the mixed dentition to the permanent dentition (mean age of 13.6 years), there was a slight, but significant, increase in intercanine width in the maxilla which demonstrated more of an increase than in the mandible. No significant changes in intercanine width were found from the permanent dentition to the young adult dentition. The intermolar width changes (Table 4) followed similar patterns except that there was not a significant increase from the mixed to the permanent dentition in the mandibular arch and that there was significant decreases in both arches from the permanent to the young adult dentitions.

Table 3. Maxillary and Mandibular Intercanine Width Increases (mm) from the Deciduous Dentition to the Young Adult Dentition (Knott[32])

	Maxillary intercanine increase		Mandibular intercanine increase	
Dental Stage	x	ρ	x	ρ
Deciduous - Mixed	2.82	0.01	2.86	0.01
Mixed - Permanent	1.96	0.01	0.34	0.01
Permanent - Young Adult	0.00	NS	-0.09	NS

x = mean increase in mm; ρ = level of significance; NS = Not Significant

Table 4. Maxillary and Mandibluar Intermolar Width Increases (mm) from the Deciduous Dentition to the Young Adult Dentition (Knott 1972)

	Maxillary intermolar increase		Mandibular intermolar increase	
Dental Stage	x	ρ	x	ρ
Deciduous - Mixed	1.83	0.01	1.45	0.01
Mixed - Permanent	1.41	0.01	0.03	NS
Permanent - Young Adult	-0.29	0.01	-0.44	0.01

x = mean increase in mm; ρ = level of significance; NS = Not Significant

In an evaluation of skeletal change, Lebret[33] studied the longitudinal growth of the palate on the dental casts of 30 individuals from 5-18 years of age using transverse and sagittal palatal contour tracings. Looking at width changes at the apex of the palatal vault near the level of the first molars, one-fourth of the subjects had no change, whereas, one-half of the subjects showed width increases ranging from 1.0 - 2.5 mm. The other one-fourth had even greater increases ranging from 3.0 - 6.0 mm with the average width increase for the entire sample being 1.9 mm. At a point 10 mm anterior to the first measurement, the increase in the width of the palatal vault tended to be less with an increase ranging from 0.0 - 3.0 mm and the average increase being 0.9 mm. The total

increase in arch width, as measured by the palatal contour tracing from first molar to first molar at the gingival level, ranged from 0.0 - 7.0 mm with an average of 4.01 mm. Subtracting 1.9 mm (growth at the midpalatal suture) from the total increase (4.01 mm), Lebret[33] attributed 2.11 mm of the total increase to growth of the alveolar processes. Ten mm anterior to this measurement, the total increase ranged from 0.0 - 6.5 mm with the average being 3.01 mm. Again, she attributed 2.11 mm of the total to alveolar growth. She concluded that the greater total growth posteriorly was due to greater growth of the midpalatal suture than the alveolar processes.

Bjork and Skieller[34] also reported an asymmetrical growth pattern of the maxillary midpalatal suture. Using metallic implants and cephalometric radiographs in 9, 4 year old boys, they were able to follow the growth of the maxilla until 16 - 20 years of age. They found a mean posterior skeletal increase of 6.5 mm in the maxilla as measured between implants placed in the infrazygomatic crest area of the maxilla. This increase was approximately three times greater than between the anterior implants placed below the anterior nasal spine on each side of the midpalatal suture. The width of the maxillary dental arch from first molar to first molar increased an average of 2.0 mm from the age of 7 years to adult age, while the intercanine width only increase an average of 0.6 mm from the age of 4 years to adult age. The increase in intermolar width was found to be, on average, approximately one-fourth of the amount of sutural growth during the observation period.

Korn and Baumrind[35] also using metallic implants in the maxilla, reported growth changes very similar to those of Bjork and Skieller.[34] In their sample of 31 children, lateral and frontal cephalograms were taken at annual intervals between the ages 8.5 and

15.5 years. Like other investigators,[33,34] Korn and Baumrind[35] observed a greater widening of the palate posteriorly with average increases between the zygomatic implants (posterior) and the incisor implants (anterior) being 0.43 mm/year and 0.15 mm/year, respectively. Theses findings demonstrated a high degree of similarity to those of Bjork and Skieller[34] who, after conversion to mm/year, reported average increases in the posterior and anterior implants of 0.42 mm/year and 0.14 mm/year, respectively. Korn and Baumrind[35] also found no evidence to support a progressive decrease in growth of the maxilla over the period studied which, again, corroborated the findings of Bjork and Skieller,[34] who stated that sutural growth in the maxilla continued until 17 years of age.

To summarize the reviewed literature on maxillary and mandibular dental changes with growth, a significant increase in maxillary and mandibular intermolar and intercanine widths was found from birth to the complete eruption of the deciduous dentition[30,31] and from the deciduous to the mixed dentitions.[30-32] From the mixed dentition to the complete eruption of the permanent dentition, excluding third molars, Bishara[30] reported significant increases in maxillary and mandibular intermolar and intercanine widths until 13 years of age, while Sillman[31] found increases in mandibular intercanine widths only until age 12 years. Knott[32] found significant increases in maxillary and mandibular intercanine and maxillary intermolar widths until the complete eruption of the permanent dentition (13.6 years), but found no significant change in the mandibular intermolar width during this period. Following the eruption of the permanent dentition, intermolar and intercanine widths either remained stable[31] or showed a slight decrease.[30,32]

For skeletal changes with growth, growth of the midpalatal suture was found to occur more posteriorly than anteriorly. Lebret[33] reported posterior and anterior growth changes of the maxilla ranging from 0.0 - 0.46 mm/year and 0.0 - 0.23 mm/year, respectively. Also reporting asymmetric growth of the maxilla, Bjork and Skieller,[34] and Korn and Baumrind[35] observed posterior midpalatal sutural growth of 0.42 mm/year and 0.43 mm/year, respectively, while anterior growth of the midpalatal suture was 0.14 mm/year and 0.15 mm/year, respectively. It was also reported that sutural growth of the maxilla tended to remain active until the late teens.[34,35]

D. RAPID MAXILLARY EXPANSION

1. INTRODUCTION. Rapid maxillary expansion (RME) appliances can be designed in many ways. However, they have certain features in common. These include a midline expansion screw (jackscrew) or spring that is attached to the teeth by means of acrylic or soldered wires. The appliance is bonded or banded to the anchor teeth.

The appliance is usually activated on a daily basis by having the patient turn the active part of the screw or spring a prescribed amount. RME appliances are generally activated 0.2 to 0.5 mm per day with active expansion time usually less than a month. Isaacson and Ingram,[6] using a Haas rapid expander, reported that single activations of the jackscrew (.2mm) produce forces ranging from 3 to 10 pounds and that multiple daily activations can produce forces up to 20 pounds. The authors also found that more force was produced by a single acitvation of the jackscrew in the older patients as compared with the younger patients. The authors reported this increase in measured force was due to an increase in the resistance of the facial skeleton of the older subjects. These high

magnitude forces are thought to maximize skeletal separation of midpalatal suture by overwhelming the suture before any orthodontic movement or physiological sutural adjustment can occur.[2,9,10] Hence, advocates of rapid maxillary expansion believe that it results in minimum dental movement (tipping) and maximum skeletal movement.[9,25]

2. **SKELETAL AND DENTAL CHANGES.** Using lateral and frontal cephalometric radiographs along with dental casts and histological sections, Debanne[36] studied the effect of palatal expansion on 9 cats. Cats were divided into four groups according to the type of orthodontic force applied (control, intermittent expansive force, continuous expansive force, and intermittent contractive force). Dentally, Debanne[36] found that the cats subjected to expansive forces showed increases in intercanine width ranging from 4.5 - 8.5 mm with the continuous expansive force group demonstrating a greater increase (7.5 and 8.5 mm) than the intermittent expansive force group (4.5 and 5.0 mm). Skeletally, the cats with palatal expansion showed a downward repositioning of the premaxilla, whereas the premaxilla was slightly elevated in the cats subjected to contractive forces. Opening of the midpalatal suture demonstrated a greater separation anteriorly than posteriorly with the intermittent expansive force group experiencing a wider separation that extended more posteriorly than the continuous expansive force group.

Thorne[37] reported on the effects of rapid palatal expansion in a group of 40 patients ranging in age from 8 - 15 years. Palatal expansion was produced by a banded expander with acrylic palatal coverage. The mean maxillary intermolar increase after expansion was 6.7 mm. In all his patients, a diastema between the maxillary central

incisors developed which spontaneously closed within a few weeks. Half of the group demonstrated a bite opening in the incisor region that ranged from 0.5 - 8 mm, whereas, only 3 cases showed bite closing. By adapting compound caps containing a long metal wire (goniometer) on the maxillary first molars of the pretreatment casts and then transferring these caps to the postreatment casts, Thorne[37] was able to demonstrate a lateral tipping of the maxillary molars following expansion. Although not measuring the amount of dental tipping, three-quarters of cases had evidence of facial tipping. There was also evidence of an accompanying increase (mean of 0.7 mm) in the width of the mandibular arch following expansion as well. By measuring the distances between the lingual root apices of the left and right first molars on occlusal radiographs, Thorne[37] found that, skeletally, the palate had widened by an average of 3.1 mm. Although showing less widening, the nasal cavity also increased (mean of 1.7 mm).

By placing vitallium implants in the infrazygomatic ridge area of the zygomatic process of the maxilla and in the palate lingual to the maxillary canines, Krebs[4] was able to study the effects of rapid palatal expansion in an 11 year old boy. Through the use of posteroanterior (PA) and lateral cephlometric radiographs, occlusal radiographs, and dental casts, he reported a greater increase between the implants lingual to the canines than between the implants in the zygomatic process. This difference between the two areas, he postulated, was due to a rotation of the maxilla in the frontal plane with a greater separation of the maxilla occurring inferiorly than superiorly. Furthermore, Krebs[4] also noticed an asymmetric separation of the maxilla in the transverse plane with the increase anteriorly being greater than the increase posteriorly.

In a latter longitudinal study using implants on 23 patients ranging in age from 8 - 19 years, Krebs[38] was able to observe the effects of rapid expansion over a 3-7 year period. He found that arch width, as measured between the maxillary first molars, remained stable after expansion and during the fixed retention period. Once retention was discontinued, however, arch width decreased over the next 4 - 5 years, but never to the point of complete relapse. The maxillary base, measured from the implants in the zygomatic processes, showed a slight relapse immediately following active expansion that amounted to approximately 0.5 mm over the course of 3 - 4 months of the retention period. After the initial relapse, the width of the maxillary base increased until 16 - 17 years of age in boys and 14 years of age in girls. He concluded that this increase was due to the normal growth of the child.

Haas[5] also reported on the effects of rapid palatal expansion in ten patients ranging in age from 9 - 18 years. A notable finding was that a gap was created between the maxillary central incisors during expansion that was approximately one-half of the amount of expansion screw activation. Haas[5] noticed that as this gap is created, the central incisors would separate with the roots diverging more than the crowns. Even when active expansion was stopped the roots continued to diverge while the crowns would start to tip mesially. As the crowns of the central incisors would come into contact, the roots would drift mesially until the original axial inclination was restored. He reported that this cycle took 4 - 6 months and hypothesized this movement was due to the presence of transeptal fibers. Haas[5] also noticed that mandibular intermolar width increased 0.5 - 2.0 mm in all ten cases suggesting a tendency for mandibular teeth to adapt to maxillary expansion by tipping laterally. In the sagittal plane, he found that point

A moved forward in all ten cases, as demonstrated by an increase (1.5 - 8.0 degrees) in the angle of convexity, an increase (1.0 -4.0 mm) in point A to facial plane, and an increase (0.0 - 2.5 degrees) of the SNA angle, and that point A moved down in five cases. In the transverse plane he reported that the earliest skeletal response to expansion is a lateral bending of the alveolar processes followed by a gradual opening of the midpalatal suture. This separation of the maxilla occurs in a triangular fashion with the apex located in the nose and the base towards the incisors. He hypothesized that this triangular opening was due to the buttressing effect of the zygomatic bones against the maxilla. Haas[5] also concluded that as the maxilla arced laterally during expansion, the palatine processes of the maxilla at the midpalatal suture would move inferiorly, thereby, lowering the palatal vault.

In contrast, Davis and Kronman[39] reported that the palatal vault did not lower as the result of rapid palatal expansion. By comparing pre and posttreatment palatal contour tracings of 26 caucasian children, they found no change in the palatal vault height, only a flattening of the palate. Corroborating the findings of Haas,[5] Davis and Kronman,[39] using lateral cephalometric radiographs in the same sample, found that point A moved forward in all cases and down, although not statistically significant, in approximately half of the cases. Although variable, there was a significant increase (0.81 degrees) in the sella nasion to mandibular plane angle which clinically manifests as an opening of the bite as reported by Thorne.[37] Also, no significant changes were noted in the bicondylar, bizygomatic, birotundal, and biorbital widths as measured on PA cephalometric radiographs in Davis and Kronman's sample.[39] Dentally, they found the average increase between the maxillary cuspids and first molars to be 3.62 mm and 6.70 mm,

respectively, with a corresponding increase in the mandibular arch of 0.57 mm and 0.55 mm. They theorized that part of the increase in maxillary intermolar width was due to facial tipping of those teeth.

In a sample of 60 patients ranging in age from 7 - 29 years who had undergone rapid expansion, Wertz,[10] using lateral cephalometric radiographs, found that the maxilla was routinely displaced downward 1 - 2 mm, but that it rarely came forward more than 1.5 mm which is in contrast to the findings of other authors.[5,39] They also found an opening of the palatal plane to the sella nasion angle, although there was much variation, and an increase in the mandibular plane angle which was usually accompanied by a decrease in the ANB angle. Following stabilization, the maxillary central incisors predominately uprighted as demonstrated by a decrease in the sella nasion to upper 1 angle. When studied in the frontal plane, Wertz[10] reported a mean increase in nasal cavity width of 1.9 mm. Also, he noticed that the separation of the maxillary halves proceeded in an arc with the fulcrum located near the frontomaxillary suture with greater separation progressing inferiorly and accompanied by a lateral bending of the alveolar processes. Finally, occlusal radiographs showed an asymmetric separation of the midpalatal suture with greater separation occurring anteriorly than posteriorly. By measuring anterior nasal spine (ANS) and posterior nasal spine (PNS), he estimated the ratio of separation of the midpalatal suture to be 3 to 2 and sometimes even 2 to 1.

Timms[40] examined the skeletal effects of rapid maxillary expansion posterior to the dental arch. Specifically, the effects produced in non tooth-bearing bones such as the palatines and the sphenoid. He measured increases in intermolar widths and interpterygoid hamular widths on a group of 32 patients ranging in age from 8 - 24 years.

The interpterygoid hamular width was measured directly on the patients by means of palpation. He found an increase in intermolar width from 6.5 - 9.5 mm and an increase in interhamular width from 3.0 - 7.0 mm with the mean percentage of interhamular width increase to intermolar width increase being 58% (range of 35 - 89%). When analyzed statistically, Timms[40] found a weak relationship (correlation coefficient no higher than +0.55) between intermolar and interhamular width increases. However, he concluded that rapid maxillary expansion does separate the palatine bones while splaying the pterygoid processes of the sphenoid bone outwards.

Filho,[25] using PA cephalometric radiographs to investigate the changes associated with rapid maxillary expansion on a group of 32 children between 5 - 11 years of age, found similar changes as reported by other investigators. Like Haas,[5] Filho[25] found the roots of the maxillary centrals diverging more than the crowns (average difference of 0.56 mm) during expansion. When comparing the amount of separation of the midpalatal suture at prosthion point to the diastema created, Filho[25] found the suture opening 1.7 mm more than the diastema, confirming the presence of the protective influence of the periodontium (transeptal fibers). He also found the increase in intermolar width to be twice as much as the increase in interincisal width and 2.5 mm greater than the increase in intertuberosity width. These findings are explained by a lateral tipping of the maxillary molars and demonstrate the orthodontic effect of palatal expansion. There was also evidence of a triangular separation of the maxilla in the frontal plane as shown by a 44% reduction in separation in the region of ANS and a 57% reduction in separation of the nasal cavity when both were compared to the separation in the alveolar region.

Ladner and Muhl[1] examined the pre and posttreatment dental cast of 30 patients (mean age 11 years 8 months) treated with rapid palatal expansion (Haas appliance) and 30 patients (mean age 11 years 11 months) treated with slow palatal expansion (quad helix). Both groups involved full fixed edgewise appliance therapy following expansion. A symmetrograph was used to trace palatal contours from upper right first molar to upper left first molar. The pre and posttreatment palatal contours were then superimposed to analyze the skeletal changes occurring within the maxilla. Dental changes, molar rotation and tipping, were analyzed through the use of a goniometer as previously described by Thorne.[37] Skeletal changes occurring in the rapid expansion group included an average skeletal expansion of 2.6 mm, as measured by palatal width change, with a positive correlation (correlation coefficient of +0.54) between upper intermolar expansion and skeletal expansion. The average ratio of skeletal expansion to upper intermolar expansion was found to be 0.46. Dental changes in the rapid expansion group included an average significant increase in upper intermolar width of 6.0 mm and a significant average change in upper molar rotation (16.5 degrees). This change in molar rotation was the result of fixed appliance therapy following expansion. There was also a significant increase in lower intermolar width (mean of 1.0 mm). No statistically significant changes were noted in the facial tipping of the upper molars.

In another comparative study, Sandikçioglu and Hazar[41] reported on the skeletal and dental changes produced by three different expansion appliances in the mixed dentition period. Thirty patients were divided into 3 groups of 10 patients each. The first group was treated with conventional fixed hyrax expansion appliances for rapid expansion, the second group had expansion accomplished with removable appliances for

semi-rapid expansion, and the third group was treated with quad-helix appliances for slow expansion. Changes were analyzed before and after expansion, and after retention by way of lateral and PA cephalometric films, occlusal films, and dental casts. The rapid palatal expansion group demonstrated significant dental and skeletal changes in all planes with the most remarkable changes occurring in the transverse plane. In the transverse plane there was a significant average increase in nasal cavity width (2.1 mm), maxillary basal width (2.7 mm), upper intercanine width (3.2 mm), and upper intermolar width (6.2 mm) with the ratio of skeletal expansion to dental expansion being 0.44. Also there was found to be no statistically significant increase in lower inter molar width. In the sagittal plane, the upper incisors tended to upright as demonstrated by an average increase in the interincisal angle of 6.9 degrees and a by a decrease in the SN to upper incisor angle. The maxilla came forward as shown by an increase in the SNA and ANB angles, with the mandible rotating down and back increasing the mandibular plane angle an average of 2.3 degrees and increasing the lower face height and average of 3.2 mm. From an occlusal view, all rapid expansion patients showed a radiographic opening of the midpalatal suture with the greatest separation occurring anteriorly.

To summarize the dental and skeletal effects of rapid maxillary expansion of the reviewed literature, changes in the sagittal and transverse planes will be analyzed. Skeletally in the sagittal plane, following expansion there was a forward movement of the maxilla in most reports[5,10,39,41] with a tendency for the maxilla to be repositioned downwards as well.[5,10,36,39] As the maxilla came forward and down, the mandible would rotate back as demonstrated by an increase in the mandibular plane angle.[10,39,41] This

backward rotation of the mandible would clinically manifest as an opening of the bite anteriorly.[37]

Skeletally in the transverse plane, the two halves of the maxilla would separate in a triangular pattern with the apex located near frontomaxillary suture and the base located in the alveolar region.[4,5,10,25] The triangular effect of expansion was thought to be due to the buttressing effects of other bones articulating with the maxilla, thereby, producing increased resistance superiorly and less resistance inferiorly.[5] Early during expansion, before the separation of the two halves, the maxillary alveolus would bend laterally which would then be followed by separation of the maxilla.[5] As the maxilla arced laterally during expansion some studies observed a lowering of the palatal vault[5] while other studies showed no change in palatal vault height.[39] Also reported was an increase in nasal cavity width.[10,37,41]

From an occlusal view, the maxillary midpalatal suture also opened triangularly with more separation occurring anteriorly than posteriorly[4,36,41] with the ratio of anterior to posterior expansion being 3 to 2 and sometimes 2 to 1.[10] Eventhough smaller than the separation anteriorly, the effect of midpalatal suture expansion was reported as posterior as the palatine bones.[40]

Dentally following expansion, the effects were opposite those seen with the midpalatal suture with a greater increase occurring posteriorly in maxillary intermolar width than anteriorly in intercanine width.[25,39,41] Part of the increase in maxillary intermolar width was found to be due to a facial tipping of the molars.[37,39] Also found was a tendency for the mandibular intermolar width to increase slightly, thereby, adapting to maxillary expansion.[5,25,37,39] During expansion separation of the midpalatal suture,

anteriorly, would produce a diastema between the central incisors[5,25,37] with the roots diverging more than the crowns.[5,25] Following expansion the diastema would spontaneously close with the incisors returning to their original inclination.[5,25,37] Sagittally, the maxillary central incisors tended to upright following expansion as demonstrated by a decrease in the SN to upper central incisor angle and an increase in the interincisal angle.[10,41] In comparing the amount of skeletal expansion to dental expansion, ratios ranged from 0.40 - 0.58[1,25,37,40] indicating that of the total amount of expansion approximately half was dental and half was skeletal.

E. SLOW MAXILLARY EXPANSION

1. INTRODUCTION. The majority of slow expansion appliances consist of a fixed palatal arch wire that is banded to the anchor teeth. The most traditionally used slow expansion appliances include the "W" arch, porter arch, a removable expansion appliance with a jackscrew, or a quad-helix. Rates of expansion generally occur at approximately 0.5 to 1.0 mm per week producing forces from several ounces to 2 pounds.

Advocates of slow expansion have questioned the need of such large rapid forces as those that are employed in RME. They believe that there is more physiologic adjustment to sutural separation producing greater stability and less relapse potential when using slower expansion.[2,3,6,12] Storey,[7] using slow expansion (0.5 to 1.0 mm per week) on rats and rabbits, found that the rate of relapse was greatly reduced and that sutural integrity had been maintained when compared to the rapid expansion group.

The question arises when using slow expansion is the amount of dental and skeletal movement seen during expansion. It was hypothesized that slow expansion

because of the constant low-grade forces generated would maximize dental movement (tipping) and minimize skeletal movement (sutural separation).

2. **SKELETAL AND DENTAL CHANGES**. Cotton[2] studied the dental and skeletal responses to slow maxillary expansion in 3 Rhesus monkeys via tantalum implants. The monkeys were expanded with a banded modified Minne expander designed to produce 1 - 2 pounds of force. The effects were analyzed by lateral and PA cephalometric radiographs and dental casts. He reported palatal separation occurring in all 3 animals with an intermolar increase from 6.9 - 9.6 mm and midpalatal suture increases ranging from 3.5 - 4.4 mm. The reported percentage of skeletal contribution to intermolar increase was about 45 - 64 percent. There was also an associated increase in mandibular intermolar width ranging from 0.9 - 1.9 mm. PA cephalometric measurements of maxillary bilateral implants indicated a greater change in the lower levels of the maxilla with progressively less change occurring more superiorly until the implants in the frontal process of the maxilla actually decreased in distance, indicating a lateral rotation or tipping of the maxilla. Cotton[2] concluded that the magnitude of midpalatal suture separation from slow expansion was comparable to rapid expansion in nonhuman primates as well as clinical patients.

In a similar study, Hicks[3] used slow expansion (banded Minne expander designed to produce 2 pounds of force) to correct posterior crossbites of 5 patients, 10 - 15 years of age. Skeletal changes were measured radiographically by means of tantalum implants. Molar angular changes were measured radiographically by means of threaded wire inserted into tubes attached to maxillary first molar bands. During treatment, only one

patient had evidence of a diastema formation, although, several showed widening of the midpalatal suture on frontal cephalograms. The mean net increase in maxillary arch width, as averaged from the increases between the first permanent molars and first and second premolars, ranged from 3.8 - 8.7 mm with a portion of the increase coming from facial tipping of the molars and maxillary segments. It was noted that compression of the periodontal ligament resulted in facial tipping of the posterior teeth during the first week of expansion. However, after the first week, the rate of dental tipping relative to expansion remained constant, indicating a bodily movement of the teeth and maxillary segments rather than a tipping.

Although not comparing the degree of orthodontic versus orthopedic changes, Harberson and Myers[42] demonstrated skeletal separation of the midpalatal suture using slow expansion. They successfully expanded ten children in deciduous and mixed dentitions who exhibited posterior crossbites with either a W or Porter arch. Occlusal radiographs taken preoperatively and at approximately 2 week intervals during treatment were evaluated by three independent observers for evidence of sutural separation. The radiographs were taken with the occlusal plane parallel to the floor with the x-ray tube positioned at a 60 degree angle to the film. The results showed that 8 of the 10 subjects had radiographic evidence of separation of the midpalatal suture. They concluded that in the cases with no radiographic evidence of sutural opening, the correction of the crossbite resulted solely from buccal tipping of the posterior teeth.

Also using a quad-helix, Bell and LaCompte[22] demonstrated separation of the midpalatal suture occurring in all their patients. The 10 subjects, age 4 years 5 months to 9 years 3 months, all had evidence of sutural separation occurring on occlusal radiographs

taken at the 2 week stage of treatment with the greatest opening anteriorly. Following 6 weeks of retention, they reported a significant average intermolar and intercanine increase of 3.9 mm and 2.3 mm, respectively, in the deciduous dentition and a significant average increase of 3.6 mm and 2.2 mm, respectively, in the mixed dentition. Statistically, there was no significant differences in the amount of expansion between the deciduous and mixed dentition groups. When considered together, there was an average increase in intermolar width of 16% and an average increase in intercanine width of 14% with no evidence of a significant mandibular intermolar increase.

In a sample of 20 patients ranging in age from 7 years 2 months to 17 years 6 months with a mean of 10 years 3 months, Frank and Engel,[43] using lateral and frontal cephalometric radiographs, also studied the effects of slow maxillary expansion using a quad-helix. Dentally, the most significant cephalometric finding was an average increase in maxillary intermolar width (5.88 mm) and intercanine width (2.74 mm) with no associated increase in mandibular intermolar width. The most significant skeletal changes included a mean increase in maxillary width, as measured from jugal point to jugal point on PA cephalometric radiographs, of 0.92 mm with 5 of the 20 cases showing increases of 2.7 mm or more. From which they concluded that moderate skeletal expansion is possible with the quad-helix, however, only slight skeletal changes were consistently demonstrated. They also concluded that for every 1 mm of skeletal expansion there was 6 mm of dental expansion. An opening of the bite was also observed as shown by a mean increase in the mandibular plane angle of 0.61 degrees.

In the previously mentioned study by Ladner and Muhl[1] comparing slow and rapid expansion, they found, dentally, in the quad helix group, a significant mean upper

intermolar increase of 5.4 mm which was comparable to the rapid expansion group. There was also a significant change in upper molar rotation (23.8 degrees), although, there was no significant difference between the two groups (due to fixed appliance therapy following expansion). Like the rapid expansion group, facial tipping in the quad helix group was found to insignificant. There was a significant increase in lower intermolar width (2.5 mm) in the quad helix group which was found to be significantly greater than in the rapid expansion group. Skeletal changes in the quad helix group include a significant average increase in palatal width (1.3 mm), however, this was significantly less than the palatal width increase in the rapid expansion group (2.6 mm). The average ratio of skeletal expansion to upper intermolar expansion for the quad helix group was found to be 0.32 which was not statistically different from the rapid expansion group (0.46).

In the comparative study by Sandikçioglu and Hazar,[41] they reported significant dental and skeletal changes following slow maxillary expansion with the quad-helix appliance. Like the rapid expansion group, the most remarkable changes were seen in the transverse plane with a significant average increase in nasal cavity width (0.9 mm), maxillary basal width (1.9 mm), upper intercanine width (4.9 mm), and upper intermolar width (5.6 mm). In comparing the amount of skeletal expansion to dental expansion, they found skeletal separation of the maxilla accounting for 34 percent of the total expansion. Unlike the rapid expansion group which demonstrated radiographic separation of the midpalatal suture in all patients, the slow expansion group exhibited separation in only half of the patients. In the half in which radiographic separation occurred, the opening was greatest anteriorly.

Using a symmetrograph[44] to produce transverse palatal contour tracings on pre and posttreatment dental casts, Lebret[45] compared the effects of slow maxillary expansion using a labiolingual appliance in 50 patients with a mean age of 11.2 years and a removable plate containing a expansion screw in 20 patients with a mean age of 9.4 years. Lebret[45] found the average total increase across the gingival margin from first molar to first molar for the labiolingual and removable plate expansion appliances to be 4.26 mm and 5.8 mm, respectively, with and average increase in the top of the palatal vault (midpalatal suture) to be 1.21 mm and 3.10 mm, respectively. Moreover, all patients treated with the removable plate appliance showed an increase in the palatal vault, whereas, only 32 of the 50 patients treated with the labiolingual appliance had evidence of an increase. She concluded that the removable plate expansion appliance produced more skeletal expansion (53 percent) than the labiolingual expansion appliance (28 percent). She further concluded that the increase in intermolar distance of the labiolingual appliance was mainly the result of a "widening" of the alveolar processes and not a separation of the midpalatal suture.

To summarize the dental and skeletal effects of slow maxillary expansion of the reviewed literature, in the sagittal plane the only observed skeletal change was an increase in the mandibular plane angle.[43] Skeletally in the transverse plane, there was a triangular separation of the two maxillary halves with the greatest opening occurring inferiorly as reported in a study on primates.[2] Most human studies did demonstrate an opening of the midpalatal suture,[1,3,22,41-43,45] however, radiographic evidence of sutural separation was variable with ranges from 50 - 80 percent of patients.[41,42] Of those that reported radiographic documentation of sutural separation, it was observed that the greatest

opening was anteriorly with less opening posteriorly.[22,41] Also an increase in nasal cavity width was reported.[41] In comparing the proportion of skeletal expansion to total expansion, ratios were found to range from 0.16 - 0.64[1,2,41,43,45] with a median ratio of 0.34, indicating slightly less skeletal change than rapid expansion procedures.

Dentally, there were significant increases in maxillary intermolar and intercanine widths with the intermolar increases being greater than the intercanine increases.[22,41,43] In contrast to rapid expansion studies, very few investigators reported the formation of a diastema between the maxillary central incisors during slow expansion with only one study reporting only 1 of 5 patients developing a diastema.[3] Adaptive increases in mandibular arch widths were variable with some authors reporting significant increases in the mandibular arch[1,2] while others reported no significant changes.[22,43] Facial tipping of the maxillary molars was observed during the first 2 weeks of expansion[3] with no significant changes in molar inclination found following fixed orthodontic appliance therapy.[1]

Comparing the dental and skeletal effects of rapid palatal expansion to those of slow palatal expansion, skeletally in the sagittal plane, slow expansion had very little effect with the only reported change being an increase in the mandibular plane angle,[43] whereas rapid expansion produced multiple changes such as a forward[5,10,39,41] and downward[5,10,36,39] movement of the maxilla with the only comparable change to slow expansion being an increase in the mandibular plane angle.[10,39,41]

Skeletally, in the frontal plane it is well documented in rapid palatal expansion studies that separation of the two maxillary halves occurs in a triangular pattern with the apex located near the bridge of the nose and the base located in the alveolar region.[4,5,10,25]

Similar to skeletal changes in the sagittal plane, skeletal changes in the frontal plane are less dramatic with slow palatal expansion with only one study in primates reporting a triangular separation of the maxilla.[2] There is also a triangular separation of the maxillary midpalatal suture when viewed occlusally in both rapid and slow expansion studies with the greatest opening occurring anteriorly and the least occurring posteriorly.[1,3,4,10,22,36,40-43,45] Again, skeletal changes were more variable in slow expansion with radiographic evidence of midpalatal suture separation occurring only some of the time.[41,42]

Dentally both rapid and slow palatal expansion produce significant increases in maxillary intermolar and intercanine widths with intermolar increases being greater than intercanine increases.[22,25,39,41,43] Also found was a corresponding increase in mandibular intermolar widths in both rapid and slow expansion,[1,2,5,25,37,39] however, two slow expansion studies reported no associated mandibular intermolar increase.[22,43] Rapid palatal expansion routinely produced a diastema between the maxillary central incisors as the midpalatal suture separated,[5,25,37] whereas, slow palatal expansion rarely if ever produced a diastema.[3] Both rapid and slow palatal expansion tipped the maxillary molars facially,[3,37,39] however, the degree of tipping occurring in each was not compared.

When comparing the amount of maxillary skeletal separation to the total intermolar increase, it was found that rapid palatal expansion produce slightly more skeletal change[1,25,37,40] than slow palatal expansion.[1,2,41,43,45] Overall the reviewed literature indicates more skeletal changes occurring all planes of space with rapid palatal expansion than with slow palatal expansion.

3. NICKEL TITANIUM PALATAL EXPANSION

a. Properties of nickel titanium alloys. Arndt[13] reported on a new type of slow palatal expansion appliance which utilizes the superelastic and shape memory phenomenons of nickel titanium wires instead of the conventional stainless steel wires. The first nickel titanium alloy, known as nitinol, was discovered in the early 1960's at the Naval Ordnance Laboratory by a researcher named Buehler.[46] The name nitinol is an acronym for nickel titanium and Naval Ordnance Laboratory. In 1971 Andreasen and Hilleman[47] introduced the orthodontic community to nitinol because of its properties of elasticity and resistance to corrosion. Their most notable finding was that nitinol wire can be tied into brackets of malposed teeth at least one third farther without undergoing any plastic deformation as compared to stainless steel and twistflex wires.

The property of nitinol to return to its original shape after a large amount of plastic deformation is termed superelasticity. The elasticity is almost 100 percent, even after being bent a large distance nitinol will spring back to its original position and still produce light continuous forces.[48] Superelastic nitinol wire not only exhibits excellent range, which is the ability to be deflected a large distance before permanent deformation occurs, it also demonstrates a lower stiffness when compared to stainless steel or beta-titanium wires.[49] The lower the stiffness of a wire the lower the force that is required to activate or bend it and the lower the force the wire will generate upon deactivation. Therefore, because of superelastic nitinol's excellent range and low stiffness, it has the ability to engage severely malposed teeth and still produce a lighter, longer lasting, constant force. Consequently, nitinol archwires can be left in the mouth the entire time needed to level the teeth with little deformation.[48]

Another property of nickel titanium wire is termed shape memory. Shape memory results when nickel titanium alloys alter atomic arrangements as a function of temperature. The temperature range over which this atomic change occurs is called the temperature transition range (TTR) and the process of alteration of atomic arrangements is known as martensitic transformation.[50] Martensitic transformation consists of two phases. When the alloy is cooled below the TTR, the martensite phase, the wire is extremely ductile and may be plastically deformed, however when the wire is heated above its TTR, the austenite phase, it will return to its original, stiffer shape (shape memory).[50-52] To obtain maximum shape recovery, the amount of deformation below the TTR should be limited to 7-8 percent.[53] Hurst[54] reported that the mean recovery for different nickel titanium wires ranged from 89-94 percent which is in contrast to the 100 percent recovery reported by other investigators[48,52,53] when deformation was limited to 7-8 percent.

Because of the reversible nature of the martensitic transformation and the ability of the manufacturer to alter the temperature transition range, the shape memory property of superelastic nickel titanium wire has proven to be clinically advantageous.

b. <u>Clinical use of nickel titanium palatal expanders</u>. In comparing the advantages and disadvantages of different expansion techniques, Arndt[13] reported the disadvantages of rapid palatal expansion to include discomfort, dependency on patient cooperation, reliance on laboratory fabrication and the intermittency of force generation. He also stated that rapid expanders are unable to correct rotated maxillary first molars which, according to Arndt,[13] occur in approximately 40% of cases. Arndt[13] further states

that slow palatal expansion will produce the best physiologic changes, however, conventional slow expansion techniques share some of the same disadvantages as rapid expansion such as intermittent force generation and inability to rotate maxillary first molars.

To overcome these disadvantages, Arndt[13] developed a temperature-activated nickel titanium palatal expander, which he claimed was able to produce light, continuous forces on the midpalatal suture while distalizing, rotating, and uprighting the maxillary first molars. The effects of the appliance are a result of the shape memory and temperature transition characteristics of nickel titanium. The nickel titanium expander has a transition temperature 94 degrees Fahrenheit. Before being inserted into the mouth, the nickel titanium expander is cooled below 94 degrees Fahrenheit. Below this transition temperature, the nickel titanium expander can easily be compressed and manipulated to facilitate placement. Once in the mouth, the nickel titanium expander will gradually warm above the 94 degree transition temperature. As it surpasses the transition temperature, the nickel titanium expander will attempt to regain its original shape (shape memory). This attempt to return to its original shape will begin to produce a light, continuous force of 180 - 300 grams (6 – 11 ounces) on the midpalatal suture and teeth.

Arndt[13] reported on five cases ranging in age from 10 - 16 years old all of which had a posterior crossbite that was corrected using a nickel titanium palatal expander. All 5 cases demonstrated an increase in their intermolar width and four out of five cases had an increase in intercanine width. Even though all the reported posterior crossbites were corrected after expansion, there was no mention of the amounts of the dental and skeletal

components of the expansion. Arndt's[13] report is currently the only relevant reference on nickel titanium expanders cited in the literature.

F. AGE INFLUENCE ON MAXILLARY EXPANSION

There is evidence, especially in slow palatal expansion, that age plays an important role in the amount of skeletal expansion. Many authors have indicated that the best time to produce palatal separation is during the pubertal growth spurt.[4,9,10] Once the child has completed their pubertal growth spurt, midpalatal suture separation is difficult.[4,9,10] This is due to the fact that as early as 12 - 13 years of age, the midpalatal maxillary suture starts forming bony interdigitations thereby locking the two maxillary halves together.[11,55]

There is evidence, however, that even earlier treatment may produce better skeletal changes. In a primate study using slow expansion, Cotton[2] found that 64 percent of the total amount of expansion was due to skeletal changes in monkeys treated in the mixed dentition, whereas, only 45 percent of the total expansion was from skeletal changes in monkeys treated in the early permanent dentition. Similarly, Hicks[3] reported that skeletal changes using slow expansion ranged from 24 - 30 percent in patients ranging from 10 years 7 months to 11 years 11 months and that his oldest patient (15 years 1 month) accounted for only a 16 percent skeletal change. Although Hicks[3] sample size is small, his findings indicate that more skeletal changes may occur in younger patients. Bell[23] also concluded that slow expansion devices such as a quad-helix appliance will increase maxillary arch width with a combination of dental and skeletal

changes in deciduous and mixed dentition stages, but that older patients may require the higher force systems of rapid expansion procedures.

In a study using rapid expansion, Krebs[38] found a tendency for the amount of expansion in the maxillary base (skeletal expansion) to decrease with age, with girls demonstrating less skeletal expansion at an earlier age than boys. He concluded that the most remarkable effect of rapid expansion occurred before and during the pubertal growth spurt and that the effect of expansion in the dental arch was less dependent on age than was the effect in the maxillary base. In contrast, Ladner and Muhl[1] reported significant negative correlation coefficients between age and upper intermolar width increase during expansion in their quad-helix group (mean age 11 years 11 months) and rapid expansion group (mean age 11 years 8 months) of -0.40 and -0.42, respectively, while not finding a statistically significant correlation between skeletal expansion and age. Likewise, Frank and Engle[43] did not find a correlation between the amount of skeletal and dental expansion and age in their sample of 20 patients, ages 7 years 2 months to 17 years 6 months, after undergoing slow expansion with a quad-helix.

Timms,[40] using rapid expansion to study the skeletal effects posterior to the maxillary dental arch in 32 subjects, age 8-24 years, reported a correlation between age and skeletal expansion. He hypothesized that the wide variation in the ratio of intermolar width increase to interhamular width increase (35-89 percent) was due to age with decreasing skeletal movement with increasing age. Statistically, Timms[40] found a remote negative correlation between age and skeletal expansion (correlation coefficient of -0.35). Also addressing the relationship between skeletal expansion and age, Filho[25] reported an average increase in nasal cavity width in his sample of 32 children ranging in age from 5 -

11 years of 2.078 mm after rapid maxillary expansion. He compared this result to those of Wertz[10] (1.9 mm) and Krebs[38] (1.4 mm) and attributed the differences between the investigators to their sample ages of which Wertz's sample[10] ranged from 7 - 29 years and Krebs's sample[38] from 8 - 19 years.

To summarize the reviewed literature on the influence of age on maxillary expansion, most authors reported a decrease in the amount of skeletal expansion with an increase in the patient's age.[1,-3,23,25,38,43] However, only one study reported a statistically significant remote negative correlation between age and skeletal expansion[40] while others found this negative correlation to be statistically insignificant.[1,43]

CHAPTER III

MATERIALS AND METHODS

A. INTRODUCTION

This prospective study will evaluate and compare the dental and skeletal effects produced by a rapid palatal expansion appliance and a temperature-activated, nickel titanium palatal expansion appliance. By analyzing pre and posttreatment dental casts and occlusal radiographs, differences between the two expansion groups will be compared for statistical significance.

B. SAMPLE

The sample consisted of 25 patients (12 RPE and 13 nickel titanium expansion). Criteria for patient selection included any patient in the primary through early permanent dentition who required palatal expansion as part of their comprehensive orthodontic treatment at the West Virginia University Department of Orthodontics (Appendix A). The clinical portion of the study was performed by several operators who are trained in the use of the expansion appliances. The RPE group was comprised of 6 males and 6 females with ages ranging from 6.67 years to 14.92 years (average of 11.13 years). 8 of the 12 RPE patients had either a unilateral or bilateral posterior crossbite. The average length of active expansion and retention combined for the RPE group was 127 days. The nickel titanium expansion group was comprised of 3 males and 10 females with ages ranging from 4.92 years to 13.66 years (average of 9.40 years). 11 of the 13 patients had either had a unilateral or bilateral posterior crossbite. The average length of active expansion and retention combined for the nickel titanium expansion group was 153 days.

C. APPLIANCES

The rapid palatal expansion appliance is a tooth-borne appliance that consists of a midpalatal jackscrew. The rapid palatal expansion appliance can either be banded or bonded to the maxillary anchor teeth. Several designs of RPE appliances have been reported in the literature. These include the banded Hyrax expander, the banded Haas expander, the bonded hygienic expander, and the all acrylic bonded expander. However, since no literature exists documenting differences in the amounts of lateral expansion utilizing different rapid palatal expansion appliances, all types of rapid expansion appliances will be included in this study.

The banded rapid palatal expander consists of a stainless steel metal framework that is soldered to bands on the maxillary first permanent molars and first premolars or in the case of a mixed dentition, the maxillary first permanent molars and primary second molars. This expansion appliance is referred to as a Hyrax-type expander (Figure 1). A variation of the Hyrax-type expander incorporates acrylic pads that contact the palatal mucosa. This is called a Haas-type expander (Figure 2).

The bonded rapid palatal expander is also designed two ways: The first incorporates a midpalatal jackscrew into a stainless steel wire framework. The framework extends from the jackscrew to the posterior dentition where it is incorporated into an acrylic splint that covers the buccal, lingual, and occlusal surfaces of the posterior teeth (Figure 3). The second design is similar to the first except that instead of a wire framework connecting the jackscrew to the acrylic splint, there is acrylic which covers the palate between the jackscrew and teeth (Figure 4)

Patients were instructed to activate the jackscrew two times per day, once in the morning and once in the evening. Each turn or activation of the jackscrew produces 0.25 mm of expansion, or 0.5 mm of total expansion per day. Expansion was considered adequate once the occlusal aspect of the maxillary lingual cusp of the permanent first molars or primary second molars contacted the occlusal aspect of the mandibular facial cusp of either the permanent first molar or primary second molar. The amount of overexpansion was designed to compensate for relapse following expansion.[56] The rapid palatal expansion appliance was left in place for approximately 3 - 6 months following active expansion for retention.

The nickel titanium expander is a tandem-loop, temperature-activated, expander as previously described by Arndt.[13] This appliance consists of tandem, temperature sensitive, .035 nickel titanium transpalatal loops which are connected bilaterally to stainless steel inserts which extend posteriorly for insertion into the lingual sheaths of the maxillary molar bands. Anteriorly, .032 stainless steel wire forms a helical loop fingerspring for lateral expansion in the canine and premolar region (Figure 5). The nickel titanium palatal expander is manufactured in eight sizes in 3mm increments. The size was chosen based on measuring the intermolar width on the pretreatment study casts from the maxillary molar lingual groove at the gingiva to the opposite lingual groove plus 3-4mm.[13] The nickel titanium palatal expander is ligated into the lingual sheaths of prefitted bands which are then cemented to both maxillary first molars (Appendix B). As in the rapid palatal expansion group, expansion was considered adequate once the occlusal aspect of the maxillary lingual cusp of either the permanent first molar or primary second molar contacts the occlusal aspect of the mandibular facial cusp of either

the permanent first molar or primary second molar. The nickel titanium expander was left in place for approximately 3 – 6 months following active expansion for retention.

In the event of appliance failure (i.e. broken or dislodged appliances) during active expansion, the appliance was reinserted and reactivated until correction of the posterior crossbite. If there was appliance failure during the retention phase of treatment, the patient was withdrawn from the study.

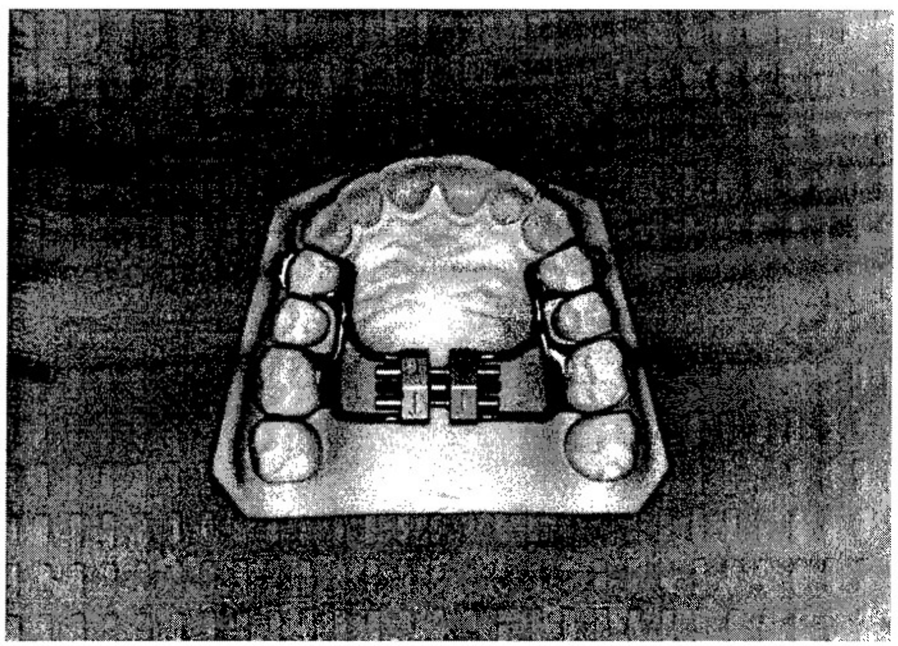


Figure 1. Hyrax-Type Expansion Appliance

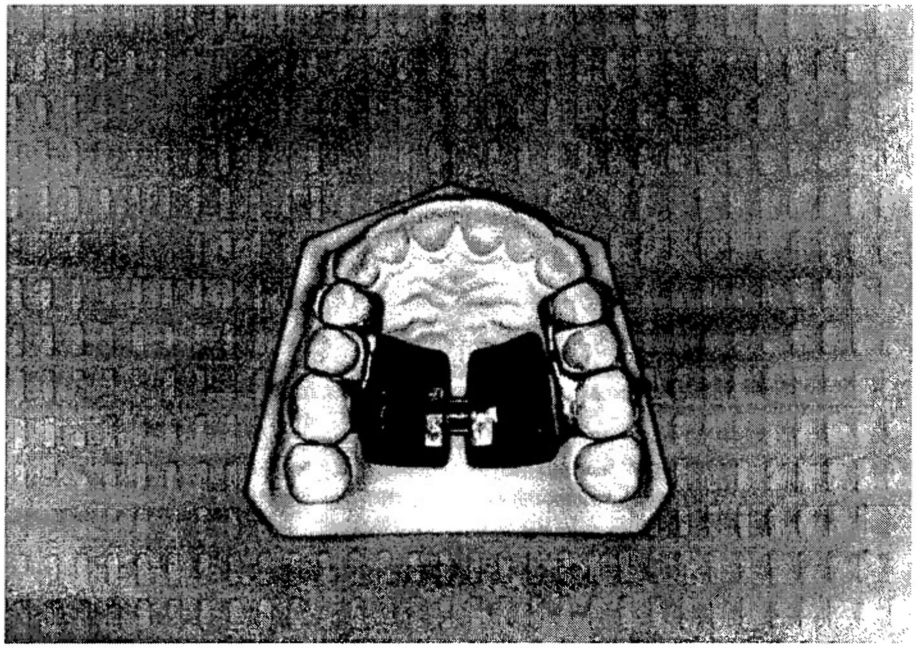


Figure 2. Haas-Type Expansion Appliance

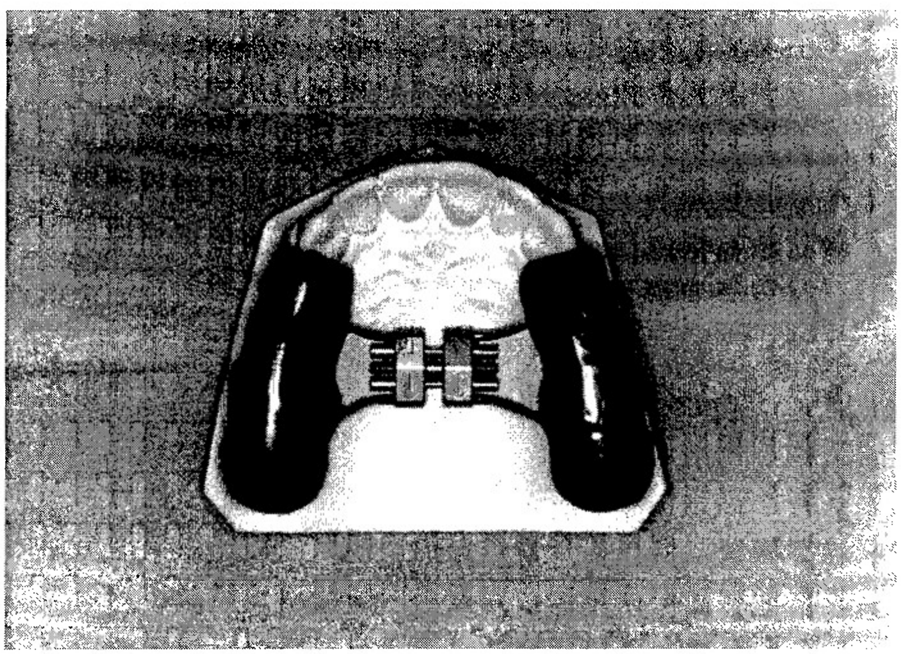


Figure 3. Hygienic Bonded Expansion Appliance

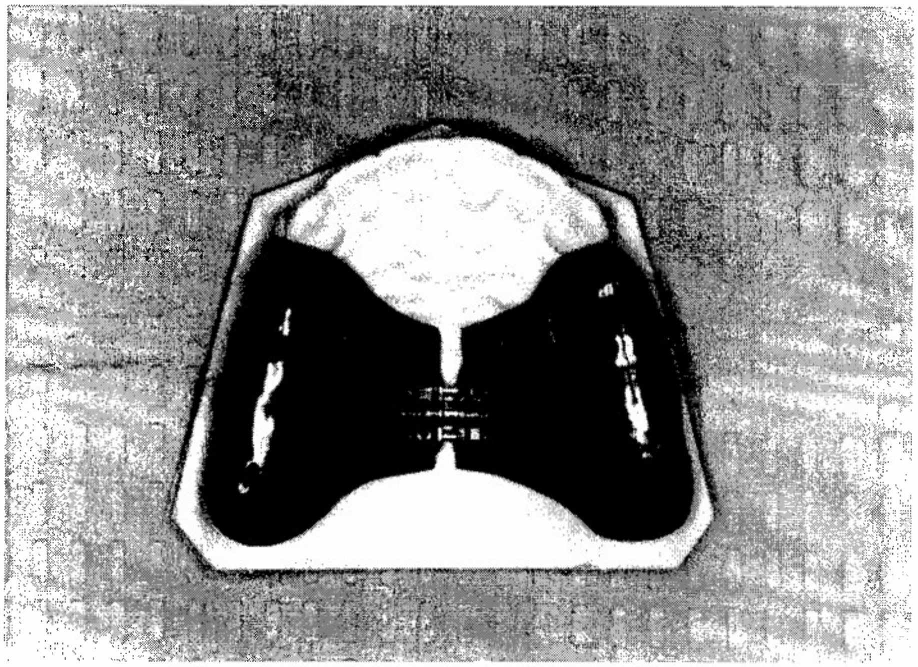


Figure 4. All Acrylic Bonded Expansion Appliance

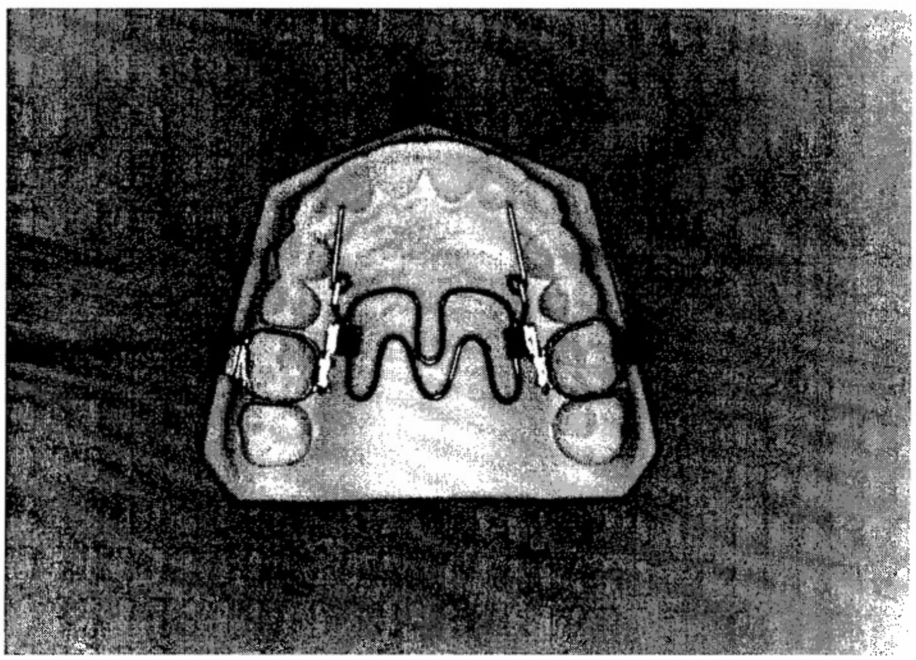


Figure 5. Nickel Titanium Expansion Appliance

D. STUDY CAST EVALUATION

All relevant patient information including age, appliance type, length of treatment, etc., was recorded before, during, and following treatment (Appendix C). Study models were taken before treatment and at the end of retention following expansion. The study models were made from alginate impressions. The impressions were sent to a commercial laboratory for pouring and trimming. The pre and posttreatment orthodontic study models were used for analysis of comparative changes in palatal width, maxillary alveolar tipping, maxillary molar tipping, maxillary molar rotation, and palatal depth as described in the following:[1]

1. <u>PALATAL WIDTH CHANGE</u>. Transverse palatal contour tracings of the casts were made using a symmetrograph as described by Korkhaus.[44] A symmetrograph which is a specialized form of a pantograph is used to copy a shape, in this case, the palatal contour of the study models to any desired scale. It consists of a sliding base with millimetric measurements on either side of the base. Incorporated into the sliding base is a rotating platform that can turn 90 degrees and in the center of the rotating platform are 3 screws to stabilize the dental casts. Perpendicular to the base is the recording plate which records the tracings produced by the pantograph arm as it traces the dental casts (Figure 6).

To compare the amount of palatal width change, the pretreatment cast is secured on the rotating platform so that the median palatal raphe is parallel to the recording plate and the occlusal plane is parallel to the base . The median palatal raphe is then traced onto the recording plate (Figure 7). This tracing is then used to latter orient the

posttreatment cast. Then the pretreatment cast is rotated 90 degrees so that the median palatal raphe is now perpendicular to the recording plate. Once rotated a distinct palatal rugae, point A, is located and a line is projected from point A perpendicular to the median palatal raphe. The point of intersection is referred to as point B (Figure 8). Next, another line is projected connecting the lowest contour of the lingual gingival margin of the first molars and where it intersects the median palatal raphe is referred to as point C (Figure 8). Using the same reference points, the transverse palatal contour is then traced to the recording plate with point C also being marked on the tracing (Figure 9). The distance from point B to point C is also recorded from the pretreatment casts.

The posttreatment cast is then placed on the rotating platform so that its median palatal raphe of the posttreatment cast is coincident with median palatal raphe tracing of the pretreatment cast. Once coincident, the posttreatment cast is rotated 90 degrees and points A and B are located. With the tracing arm located at point B the cast is then moved via the sliding base according to the measurement made on the pretreatment cast (point B to point C) so that tracing arm is now located at point C. The transverse palatal contour which is now locate at the same place as the transverse palatal contour of the pretreatment cast is traced to the recording plate along with point C.

The pre and posttreatment tracings are then superimposed on the horizontal palatal shelves and at the curvature joining the left alveolar process and palatal shelf. The difference between the two raphes (A) is the amount of palatal width change to the right (Figure 10). The same procedure is repeated on the right side. The difference between the two raphes (B) is the amount of palatal width change to the left (Figure 11). The right

and left side differences in the median palatal raphes are then added (A + B) to indicate the total amount of skeletal expansion across the midpalatal suture.

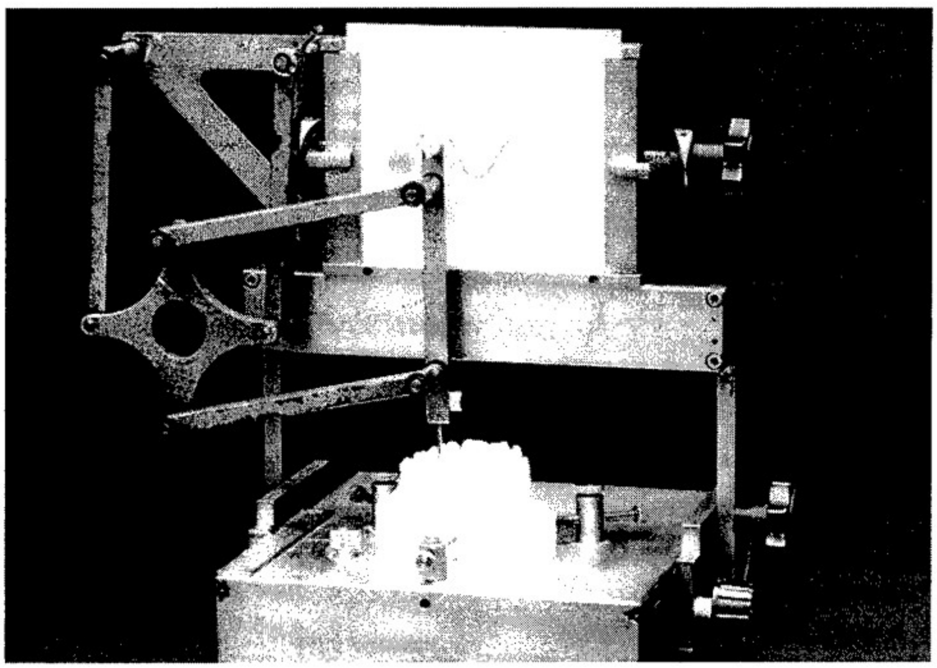


Figure 6. Symmetrograph

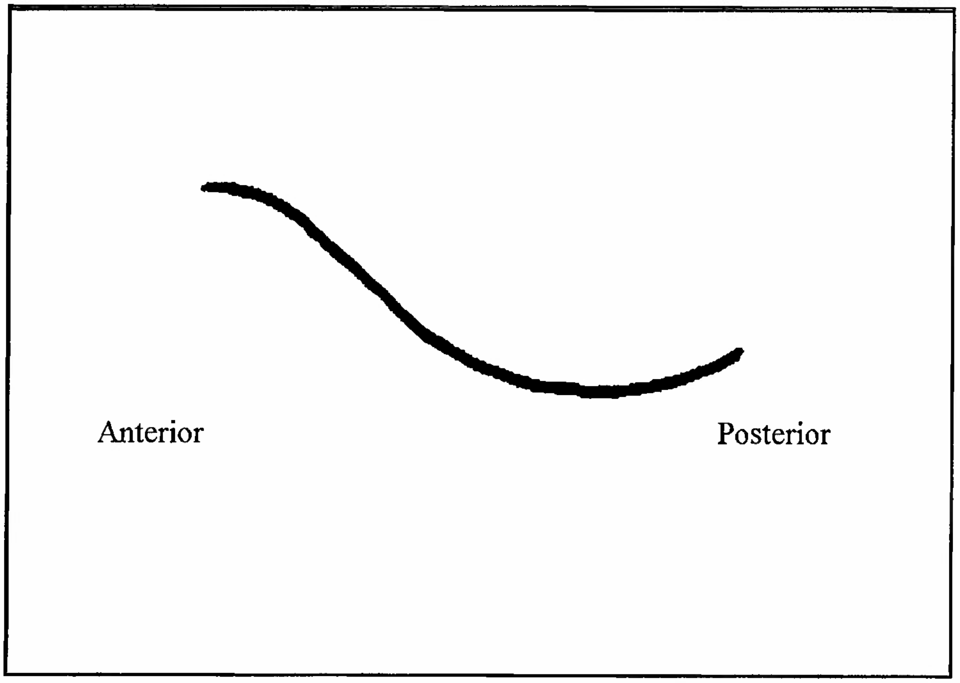


Figure 7. Anterior-Posterior Tracing of Median Palatal Raphe Using a Symmetrograph

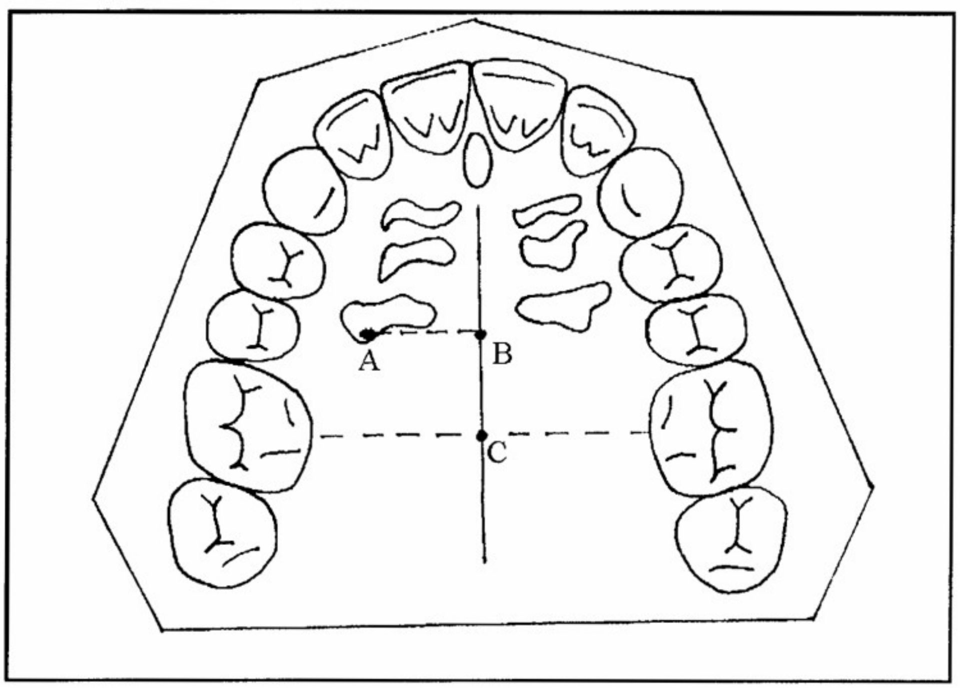


Figure 8. Identification of Dental Cast Landmarks

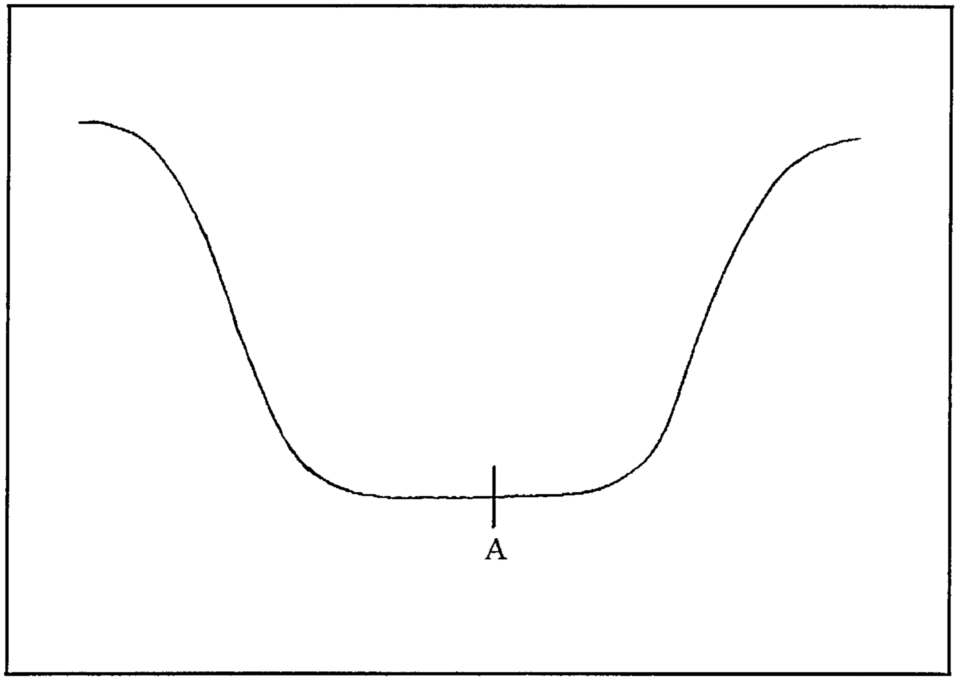


Figure 9. Transverse Palatal Contour Tracing with Identification of Median Palatal Raphe(A)

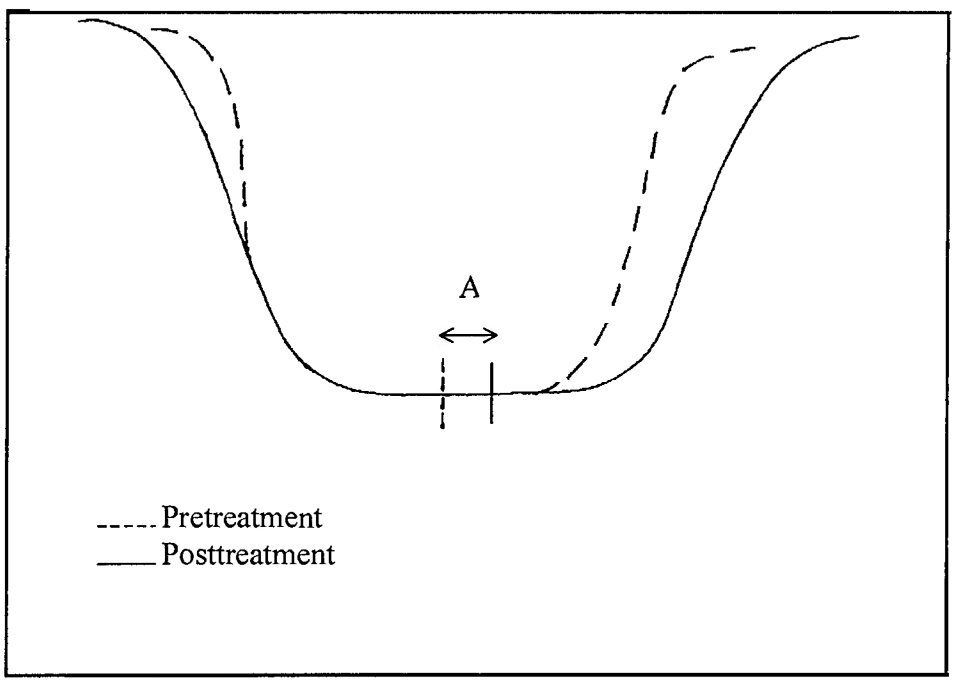


Figure 10. Measurement of Palatal Width Change to the Right (A)

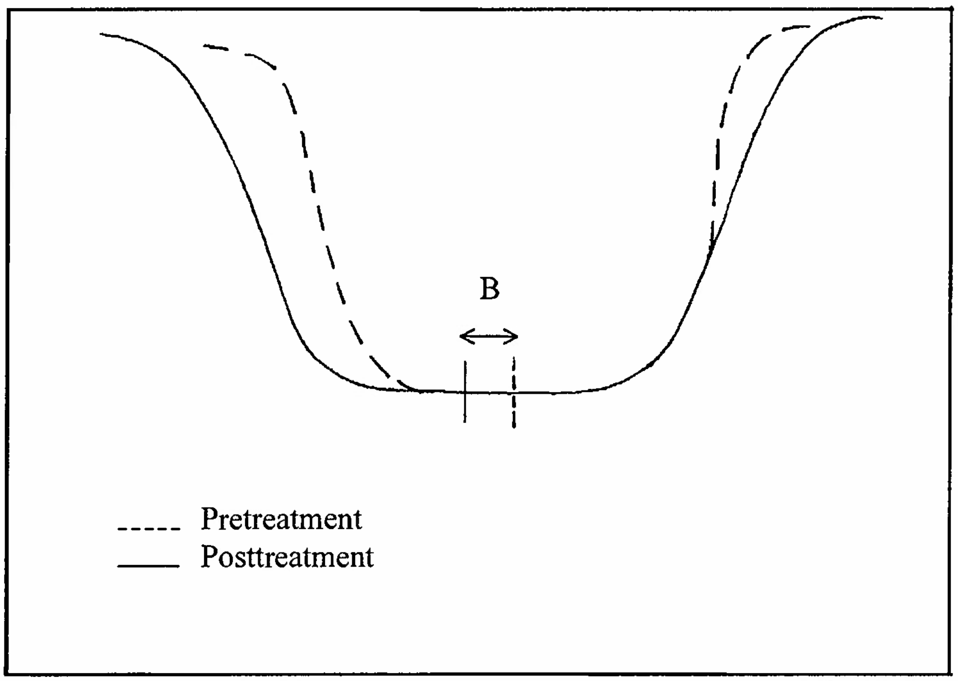


Figure 11. Measurement of Palatal Width Change to the Left (B)

2. <u>MAXILLARY ALVEOLAR TIPPING.</u> Transverse palatal contour tracings were made as described above. A line was drawn from the midpoint of the curve of the junction of the alveolar process and tooth to the midpoint of the curve of the junction of the alveolar process and palatal shelf. This was done for both the right and left sides of the pre and posttreatment tracings (Figure 12). The pre and posttreatment tracings were then superimposed on the lines representing the left alveolus. The angle formed between the lines on the right side (A) indicate the total amount of alveolar tipping in degrees (Figure 13).

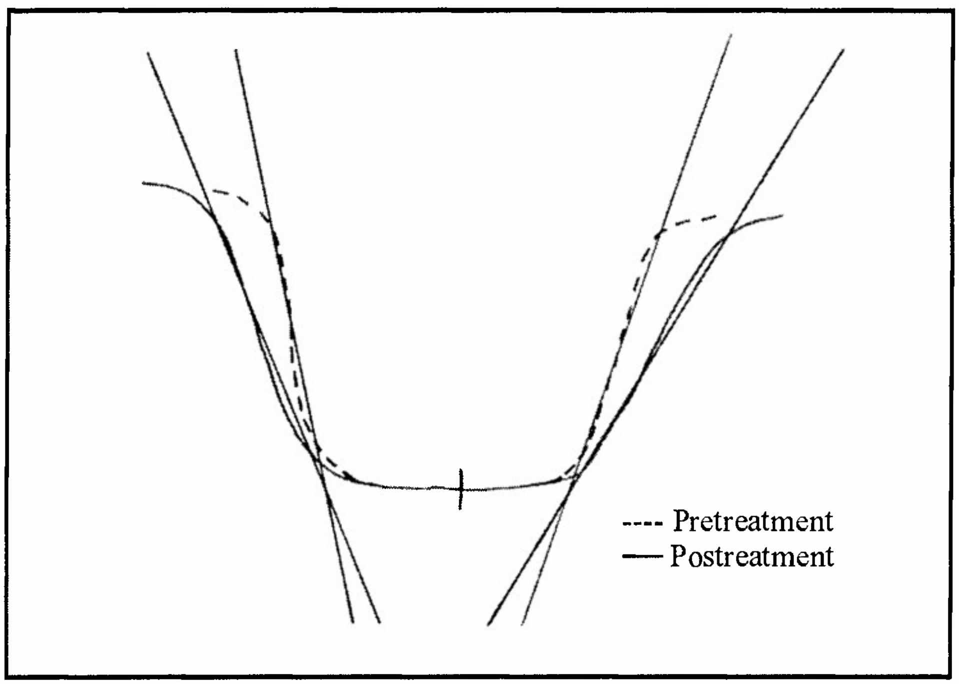


Figure 12. Construction of Lines Representing Pre and Posttreatment Alveolar Processes

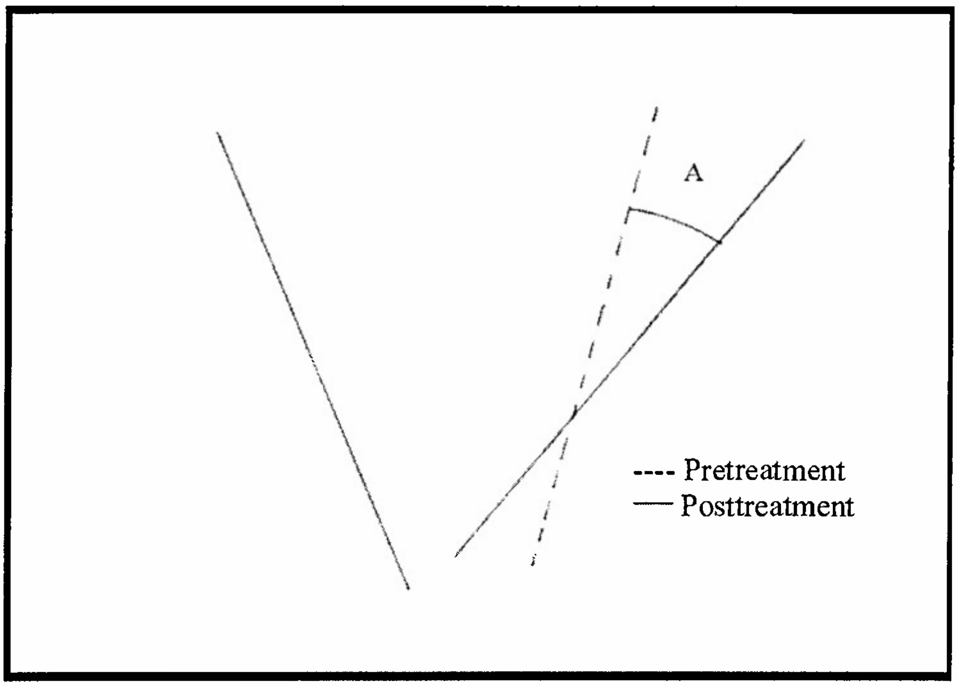
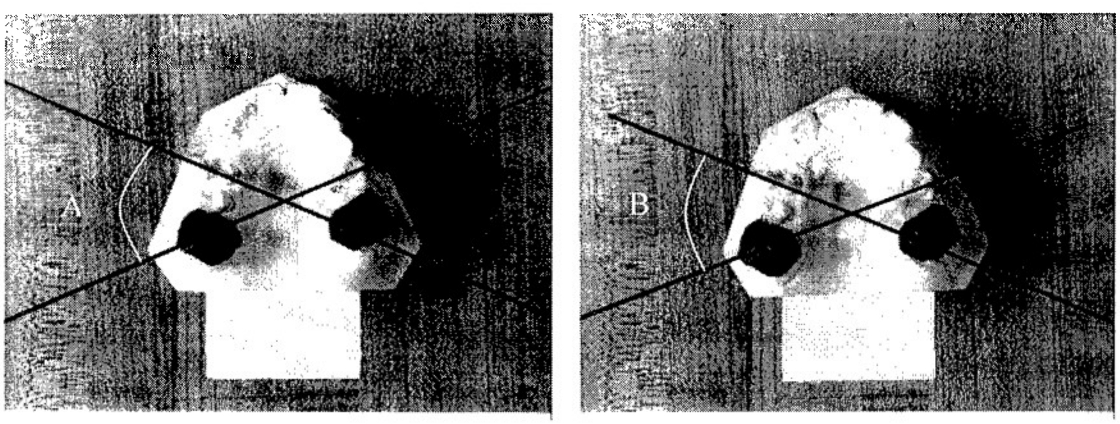


Figure 13. Superimposition of Pre and Posttreatment Alveolar Lines on the Left Side with the Total Amount of Alveolar Tipping Indicated by Angle A

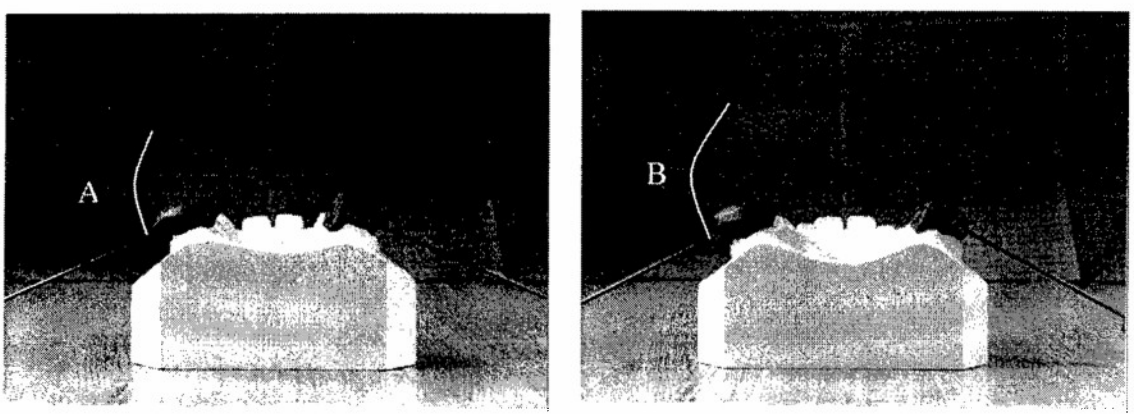
3. <u>MAXILLARY MOLAR ROTATION</u>. To evaluate the amount of maxillary molar rotation, polyvinylsiloxane impression putty caps were placed on the maxillary first molars of the pretreatment dental casts. While the putty was still soft, orthodontic wire (.040) was inserted into the putty of each first molar so that they were parallel to the occlusal plane and intersected at a 45 degree angle when viewed from the directly above the casts. To minimize distortion of the wires, a photograph was then taken from above the cast with a 200mm lens at a distance of 175cm (wire to film). The putty caps with wires (goniometers)[37] were then transferred to the posttreatment casts and the photograph was repeated. The angle formed on the posttreatment casts (B) minus the angle formed on the pretreatment casts (A) will then be a measurement of the amount of molar tipping (Figure 14). A positive change indicated mesiobuccal rotation and a negative change indicated mesiolingual rotation.



Pretreatment Posttreatment

Figure 14. Measurement of Molar Rotation (Angle B Minus Angle A)

4. <u>MAXILLARY MOLAR TIPPING</u>. To evaluate the amount of maxillary molar tipping, polyvinylsiloxane impression putty caps were placed on the maxillary first molars of the pretreatment dental casts. While the putty was still soft, orthodontic wire (.040) was inserted into the putty of each first molar so that they were perpendicular to the occlusal plane and intersected at a 45 degree angle when viewed from the heal of the casts. To minimize distortion of the wires, a photograph was then taken from the heal of the cast parallel to the median palatal raphe with a 200mm lens at a distance of 175cm (wires to film). The putty caps with wires (goniometers)[37] were then transferred to the posttreatment casts and the photograph was repeated. The angle formed on the posttreatment casts (B) minus the angle formed on the pretreatment casts (A) will then be a measurement of the amount of molar tipping (Figure 15). A positive change indicated buccal crown tip and a negative change indicated lingual crown tip.



Pretreatment Posttreatment

Figure 15. Measurement of Molar Tipping (Angle B Minus Angle A)

When evaluating molar tipping with the method just presented, a potential source of error is evident. This error is caused by the effect of molar rotation on tipping. For example, rotations of the molars will cause an apparent change in the amount of tipping even though no tipping had occurred. For this reason, a jig was constructed to evaluate the effect of rotation on tipping (Figure 16). The wires on the jig were set up and evaluated in the same manner as described in the previous section for evaluating maxillary molar tipping. The wires were rotated and evaluated via photographs every 5 degrees up to 50 degrees. Three trials were run with the distance between the two centers of rotation of the jig set at 40 mm and three trials were run with the distance set at 86 mm. This problem will be discussed in greater detail in Chapter IV.

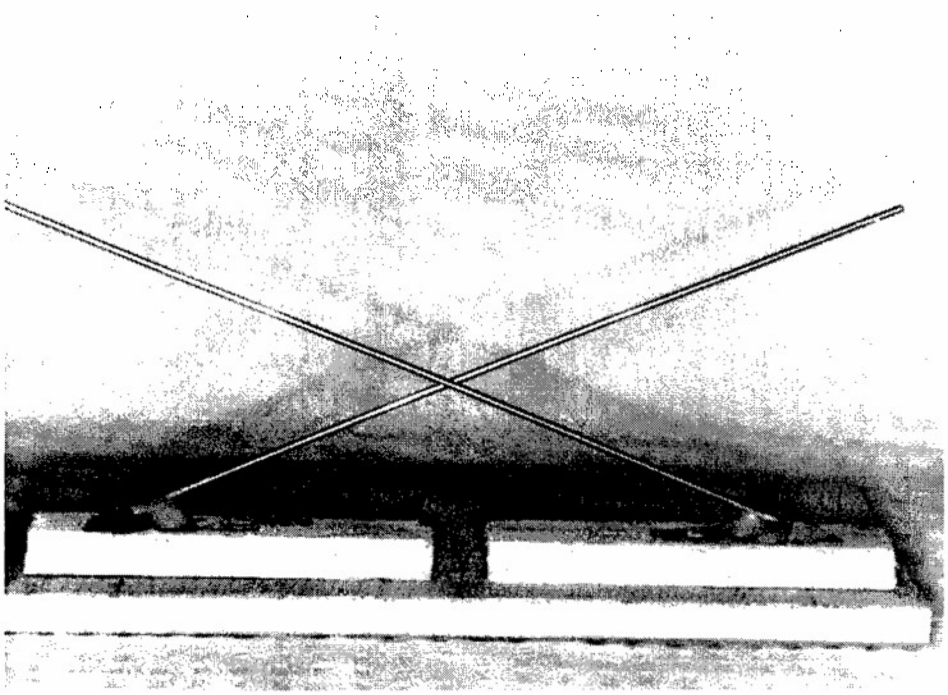
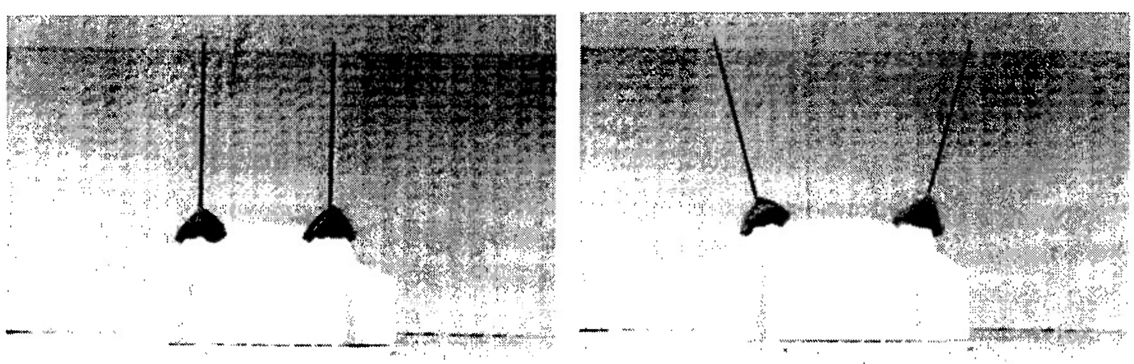


Figure 16. Jig used to evaluate the effect of rotation on tipping

Because of this source of error, a second method was employed to evaluate the tipping of the molars. Instead of placing the wires at a 45 degree angle as seen in Figure 15, the wires were placed over the central fossa of the first molar, perpendicular to the base of the dental cast (Figure 17). A photograph was then taken in the exact manner as previously discussed for the first method of evaluating molar tipping. Tracings of the pre and posttreatment wires were then made. The left side wires of the pre and posttreatment tracings were then superimposed on each other and the angle formed by the wires on the right side was the total amount of molar tipping. Figure 13, showing superimposition for determination of alveolar tipping, demonstrates the same procedure used for molar tipping. Molar tipping data used for statistical analysis and comparison was evaluated using this method.



Pretreatment Posttreatment

Figure 17. Alternative Method for Evaluating Molar Tipping

5. <u>PALATAL DEPTH</u>. Palatal depth changes were measured using a square sheet of hard clear acrylic (2mm) which extended beyond the teeth. A rectangular orthodontic wire (.040) was inserted perpendicularly into the acrylic so it can slide up and down (Figure 18). A horizontal line was drawn across the acrylic so it intercepted the sliding wire. This horizontal line was positioned across the mesiolingual cusps of the first molars for reproducible alignment. The acrylic was placed on the occlusal surface of casts so it contacted the most prominent cusp of the first molars bilaterally and the first contact mesially. The wire was then extended until it touched the palate and a measurement was recorded in millimeters. The pre and posttreatment measurements were then used to assess palatal depth changes.

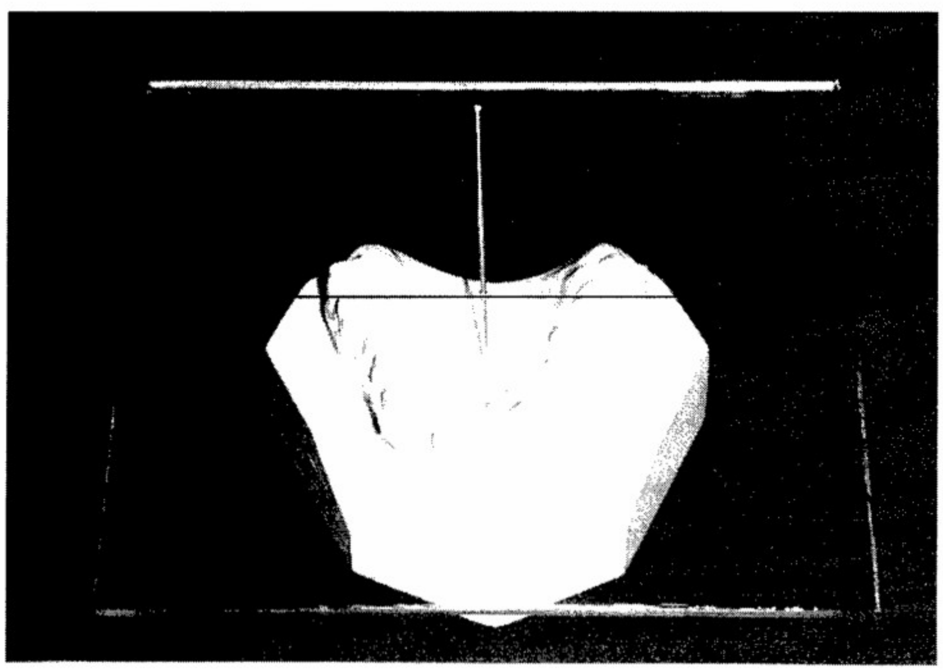


Figure 18. Measurement of Palatal Depth

E. RADIOGRAPHIC EVALUATION

Maxillary occlusal radiographs were taken prior to treatment and two weeks following active expansion. The radiographs were taken with maxillary occlusal plane parallel to the floor and the x-ray cone positioned at a 60 degree angle to the film and parallel to the patient's facial midline. Four part-time orthodontic faculty who are experienced in the use of palatal expansion procedures were used to evaluate and compare the patient's pretreatment radiograph to the radiograph taken after two weeks. The radiographs were evaluated under standard viewing prodedures. The examiners were given an evaluation sheet (Appendix D) and were asked if they saw any evidence of sutural opening between the patient's pretreatment radiograph and the radiograph taken after two weeks. The examiners answered either "yes" or "no" for evidence of midpalatal sutural opening. No attempt was made to evaluate the amount of midpalatal sutural opening. The evaluators had no connection to this study nor were they given any information regarding the time interval between radiographs. Evidence of sutural expansion will be demonstrated by a radiolucent widening of the suture.[42]

F. ERROR STUDY

To test the reproducibility of the measurements described above, all measurements will be completed twice on ten sets of casts with three weeks between trials. The differences between trials will be tested for significance using a paired *t*-test. Any differences will be considered significant at $p < .05$.

G. ANALYSIS OF DATA

Significant changes in the amount of intermolar width, palatal width, maxillary alveolar tipping, maxillary first molar tipping, maxillary first molar rotation, and palatal depth in both the rapid expansion group and the nickel titanium expansion group will be evaluated using a paired *t*-test. The level of significance will be set at $p < .05$. The correlation between age, length of treatment and the variables mentioned above will also be tested for the two expansion groups using a Matrix of Pearson Correlation Coefficient. The correlations will be significant at $p < .05$. Also, a Stepwise Multiple Regression Analysis will be used to evaluate the possible factors related to the overall amount of expansion.

CHAPTER IV

RESULTS AND DISCUSSION

A. RESULTS

1. **ERROR STUDY**. All measurements were completed twice on ten sets of casts (5 RPE and 5 nickel titanium palatal expansion) with three weeks between trials. Paired *t*-tests (Appendix H) showed no significant differences ($p < .05$) between trials for any of the measurements (Table 5).

Table 5. Error Study Results

Measurement	Mean Difference	Standard Error	*t* value	*p* value
PWC (mm)	0.01	0.038	0.235	0.819
IMWC (mm)	0.10	0.062	1.623	0.139
PDC (mm)	0.02	0.051	0.331	0.748
AT (degrees)	0.1	0.179	0.557	0.591
MR (degrees)	0.4	0.520	0.768	0.462
MT (degrees)	0.3	0.559	0.537	0.604

PWC = palatal width change; IMWC = intermolar width change; PDC = palatal depth change; AT = alveolar tipping; MR = molar rotation; MT = molar tipping

2. <u>THE EFFECT OF MOLAR ROTATION ON MOLAR TIPPING.</u> Tables 6 and 7 show the results of the jig trials used to determine what effect rotation had on tipping and vice versa when using the methodology previously described (Figures 14 and 15). As rotation occurs the initial angle (45 degrees) between the wires increases giving the false impression that tipping had occurred even though there was no tipping. The greater the rotation the greater the apparent tipping of the wires. For example, a 10 degree rotation will produce an increase in the apparent tipping of approximately 1 degree whereas, a 50 degree rotation will produce an apparent increase in tipping of approximately 20 degrees. Mathematically, the exact effect of rotation (β) on the apparent tipping angle (δ) can be computed using the formula (Appendix E):

$$\delta = 2\left[\tan^{-1}\left(0.4142\sqrt{1+(\tan\beta)^2}\right)\right]$$

Figure 19 graphically demonstrates the effects of rotation on tipping with all six trial runs plotted along with the theoretical curve which is represented by the previously mentioned formula.

Table 6. Influence of Rotation on Tipping (40 mm Group)

	40 mm GROUP		
	RUN 1	RUN 2	RUN 3
ROTATION (degrees)	Apparent tipping angle (degrees)	Apparent tipping angle (degrees)	Apparent tipping angle (degrees)
0	45	45	45
10	46	46	46
15	47	47	47
20	47	48	48
25	48	49	49
30	51	51	50
35	54	53	53
40	56	56	56
45	61	60	60
50	65	65	66

Table 7. Influence of Rotation on Tipping (86 mm Group)

	86 mm GROUP		
	RUN 1	RUN 2	RUN 3
ROTATION (degrees)	Apparent tipping angle (degrees)	Apparent tipping angle (degrees)	Apparent tipping angle (degrees)
0	45	45	44
10	45	45	45
15	46	46	46
20	47	47	47
25	49	49	49
30	50	51	50
35	53	53	53
40	56	57	57
45	61	61	61
50	66	65	65

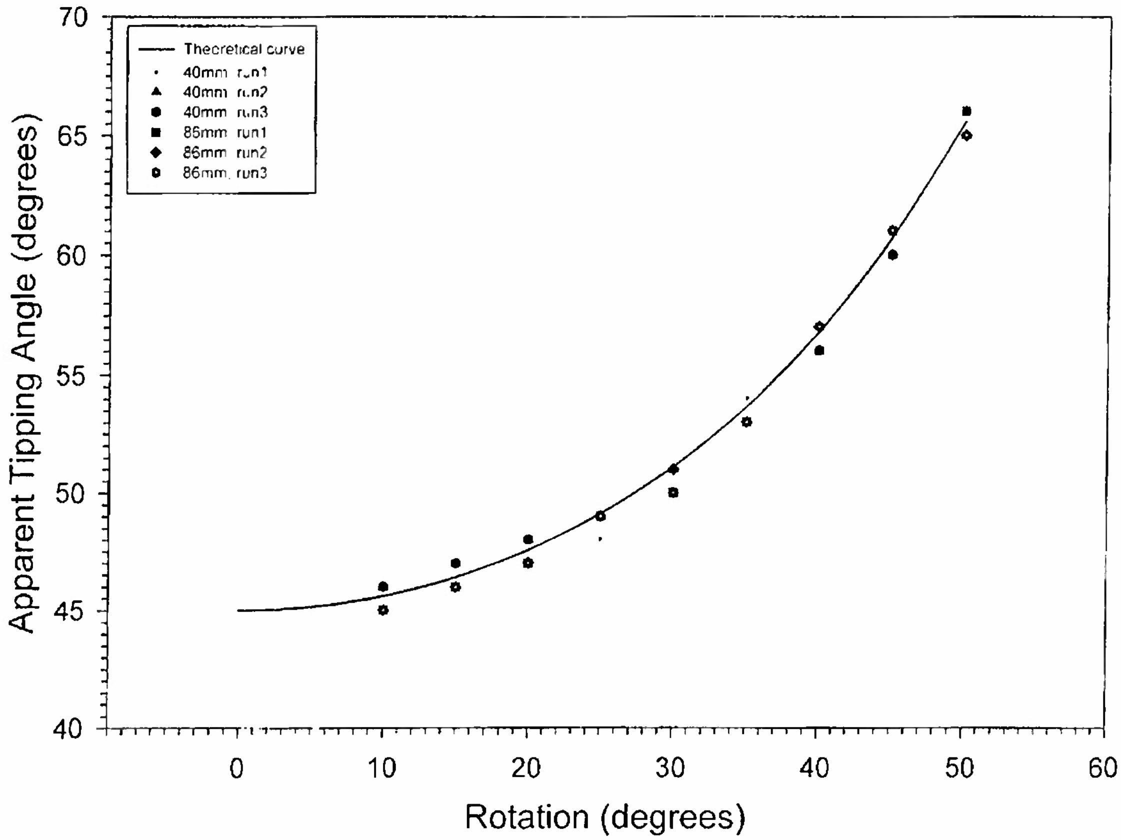


Figure 19. Graphic representation of the effect of rotation on the apparent tipping angle

3. **<u>MAXILLARY CHANGES.</u>** All raw data from this study can be found in Appendix F and G. Tables 8 and 9 show the mean changes, standard deviations, and minimum and maximum changes of the RPE group and the NITI group, respectively, following expansion. Paired *t*-tests (Appendix I and J) were used to see if the changes that occurred were significant ($p < .05$)

The RPE group showed statistically significant increases in palatal width (mean increase of 1.41 mm), intermolar width (mean increase of 4.76 mm), alveolar tipping (mean increase of 5.08 degrees), and molar tipping (mean increase of 6.08 degrees). The amount of palatal depth change (mean change of –0.07 mm) and molar rotation (mean rotation of 1.58 degrees) in the RPE group were found to be statistically insignificant. The percentage of skeletal expansion, as defined as the amount of palatal width change divided by the intermolar width change, was found to be 28% in the RPE group.

In the NITI group, statistically significant increases were found in palatal width (mean increase of 0.99 mm), intermolar width (mean increase of 6.26 mm), alveolar tipping (mean increase of 6.61 degrees), molar rotation (mean increase of 26.61 degrees), and molar tipping (mean increase of 11.69 degrees). Palatal depth demonstrated no statistically significant change (mean change of –0.04 mm) while the percentage of skeletal expansion was found to be 16% in the NITI group.

Table 8. Changes Occurring in the RPE Group

Measurement	Mean	Standard Deviation	Minimum	Maximum	P value
PWC (mm)	1.41*	1.09	0.00	3.56	0.001
IMWC (mm)	4.76*	1.55	2.42	7.31	<0.0001
RATIO PWC/IMWC	0.28	0.17	0.00	0.53	
AT (degrees)	5.08*	5.43	-4.00	13.00	0.008
PDC (mm)	-0.07	0.89	-1.37	1.39	0.800
MR (degrees)	1.58	2.74	-2.00	6.00	0.071
MT (degrees)	6.08*	6.25	-2.00	15.00	0.006

PWC = palatal width change; IMWC = intermolar width change; PDC = palatal depth change; AT = alveolar tipping; MR = molar rotation; MT = molar tipping
* = significant change from pre to post treatment

Table 9. Changes Occurring in the NITI Group

Measurement	Mean	Standard Deviation	Minimum	Maximum	P value
PWC (mm)	0.99*	0.45	0.33	2.03	<0.0001
IMWC (mm)	6.26*	1.65	3.40	8.62	<0.0001
RATIO PWC/IMWC	0.16	0.08	0.07	0.33	
AT (degrees)	6.61*	3.73	1.00	12.00	<0.0001
PDC (mm)	-0.04	0.70	-1.44	0.98	0.829
MR (degrees)	26.61*	16.29	6.00	72.00	<0.0001
MT (degrees)	11.69*	10.47	-3.00	28.00	0.0017

PWC = palatal width change; IMWC = intermolar width change; PDC = palatal depth change; AT = alveolar tipping; MR = molar rotation; MT = molar tipping
* = significant change from pre to post treatment

4. <u>COMPARISON OF MAXILLARY CHANGES</u>. Because the exact amount of appliance activation for both the NITI and RPE expansion groups was not determined, a direct statistical comparison was deemed impractical. For this reason, only a general, nonstatistical comparison was attempted.

Both the NITI and RPE groups produced statistically significant increases in maxillary intermolar width of 6.26 mm and 4.76 mm, respectively, with the NITI group demonstrating 1.5 mm more of intermolar width increase. Likewise, both the NITI and RPE groups also produced a statistically significant increase in palatal width of 0.99 mm and 1.41 mm, respectively. However, more of an increase was noted in the RPE group than in the NITI group. Therefore, the percentage of skeletal expansion as related to overall expansion was found to be greater in the RPE group (28%) than in the NITI group (16%).

Both the NITI group and RPE group produced statistically significant increases in the amounts of buccal alveolar tipping (6.61 degrees and 5.08 degrees, respectively) and buccal molar tipping (11.69 degrees and 6.08 degrees, respectively) with the NITI group demonstrating slightly more buccal tipping of the alveolus and almost twice as much tipping of the molars when compared to the RPE group. A difference between the two groups was found in the ability to rotate molars with the NITI group producing a statistically significant change in molar rotation of 26.61 degrees and the RPE group producing an statistically insignificant change of only 1.58 degrees. Finally, both the NITI and RPE groups demonstrated no statistically significant changes in depth of the palate of –0.04 mm and –0.07 mm, respectively.

Table 10. Comparison of Changes between the NITI Expansion Group and the RPE Group

	NITI GROUP		RPE GROUP	
Measurement	Mean	Standard Deviation	Mean	Standard Deviation
PWC (mm)	0.99	0.45	1.41	1.09
IMWC (mm)	6.26	1.65	4.76	1.55
RATIO PWC/IMWC	0.16	0.08	0.28	0.17
AT (degrees)	6.61	3.73	5.08	5.43
PDC (mm)	-0.04	0.70	-0.07	0.89
MR (degrees)	26.61	16.29	1.58	2.74
MT (degrees)	11.69	10.47	6.08	6.25

PWC = palatal width change; IMWC = intermolar width change; PDC = palatal depth change; AT = alveolar tipping; MR = molar rotation; MT = molar tipping

5. <u>CORRELATION OF MAXILLARY CHANGES.</u> Tables 11 and 12 show Matrix of Pearson Correlation Coefficients (*r*) for palatal width change, intermolar width change, palatal depth change, alveolar tipping, molar rotation, molar tipping, age, and the length of treatment for the RPE group and NITI group, respectively (Appendix L and M).

In the RPE group, 4 of the 28 correlations were found to be statistically significant ($p < .05$). Both palatal width change and alveolar tipping demonstrated a statistically significant positive correlation with intermolar width change of 0.62 and 0.67, respectively, while palatal width change and molar rotation also showed a statistically significant positive correlation ($r = 0.61$). A statistically significant negative correlation was found between buccal tipping of the alveolus and palatal depth change ($r = -0.58$). No statistically significant correlation was found between age and treatment time and any of the variables.

In the NITI expansion group only 1 of the 28 correlations was found to be statistically significant ($p < .05$) with palatal depth change and palatal width change having a statistically significant negative correlation ($r = -0.58$). Palatal width change, alveolar tipping, and molar tipping all demonstrated no statistically significant correlation with intermolar width change and like the RPE group, no statistically significant correlation was found between age and treatment time and any of the variables in the NITI group.

Table 11. Matrix of Pearson Correlation Coefficients for Changes in the RPE Group

	PWC	IMWC	PDC	AT	MR	MT	AGE
PWC	1.00						
IMWC	0.62*	1.00					
PDC	0.14	-0.23	1.00				
AT	0.22	0.67*	-0.58*	1.00			
MR	0.61*	0.14	0.17	-0.26	1.00		
MT	0.19	0.42	-0.35	0.50	-0.13	1.00	
AGE	-0.11	0.42	-0.09	0.28	-0.55	0.12	1.00
TREATMENT TIME	0.41	0.25	0.16	-0.13	0.45	-0.16	-0.21

PWC = palatal width change; IMWC = intermolar width change; PDC = palatal depth change; AT = alveolar tipping; MR = molar rotation; MT = molar tipping
* = significant correlation

Table 12. Matrix of Pearson Correlation Coefficients for Changes in the NITI Expansion Group

	PWC	IMWC	PDC	AT	MR	MT	AGE
PWC	1.00						
IMWC	0.40	1.00					
PDC	-0.58*	-0.11	1.00				
AT	0.11	0.10	-0.42	1.00			
MR	-0.31	-0.01	-0.09	0.25	1.00		
MT	-0.08	0.26	0.28	-0.28	-0.22	1.00	
AGE	-0.30	-0.01	0.06	-0.07	0.29	0.23	1.00
TREATMENT TIME	-0.29	0.08	-0.01	0.18	0.51	-0.42	0.03

PWC = palatal width change; IMWC = intermolar width change; PDC = palatal depth change; AT = alveolar tipping; MR = molar rotation; MT = molar tipping
* = significant correlation

6. <u>STEPWISE MULTIPLE REGRESSION ANALYSIS.</u> In order to explain the relationship between the total amount of dental expansion (intermolar width change) and factors that might affect the total expansion, a stepwise multiple regression analysis (Appendix N and O) was performed for the RPE group and the NITI expansion group. Intermolar width change was selected as the response variable with palatal width change, alveolar tipping, molar tipping, and patient's age, selected as the predictors.

Table 13 shows the results of the regression analysis for the RPE group. Alveolar tipping was selected as the best predictor of intermolar width change (R^2 = 0.4476) followed by palatal width change, and molar tipping. All three predictors were found to be statistically significant contributors to the regression model. These three factors together explained 82% of the variability in the total amount of expansion (intermolar width change) in the RPE group. Age was found not to be a statistically significant predictor of the total amount of expansion

Table 14. shows the results of the regression analysis for the NITI expansion group. The only predictor that met the 0.250 significance level for inclusion into the regression model was palatal width change, which wasn't even a statistically significant (p = 0.1771) contributor to the model. Palatal width change explained only 16% of the variability in the total amount of expansion in the NITI group. The other predictors, alveolar tipping, molar tipping and age, were not statistically significant factors in explaining the total amount of expansion in the NITI group.

Table 13. Stepwise Multiple Regression Analysis for the RPE Group

STEP	PREDICTOR	SIGNIFICANCE	R^2
1	AT	0.0173	0.4476
2	PWC	0.0296	0.6827
3	MT	0.0344	0.8247

PWC = palatal width change; AT = alveolar tipping; MT = molar tipping

Table 14. Stepwise Multiple Regression Analysis for the NITI Group

STEP	PREDICTOR	SIGNIFICANCE	R^2
1	PWC	0.1771	0.1590

PWC = palatal width change

7. RADIOGRAPHIC ANALYSIS. Table 15 shows the results of the analysis of occlusal radiographs. In the RPE group, 9 out of the 12 total patients had occlusal radiographs available for evaluation. In all 9 patients in the RPE group, opening of the midpalatal suture was demonstrated, as indicated by a "yes" response, 100% of the time (36 out of 36 responses).

In the NITI group, 12 out of the 13 total patients had occlusal radiographs available for evaluation. The nickel titanium expansion group demonstrated opening of the midpalatal suture in 85.42% of the responses (41 out of 48 responses) with 14.58% of the responses (7 out of 48 responses) showing no evidence of sutural opening. Individual evaluator variation was observed in the nickel titanium expansion group with evaluator 1 and 2 reporting sutural opening in 75% (9 out of 12) of the responses, evaluator 3 reporting 100% opening (12 out of 12) and evaluator 4 reporting opening of the midpalatal suture in 92% (11 out of 12) of the responses. Chi-square analysis (Appendix K) of all responses showed a statistically significant difference (p = .017) in radiographic evidence of midpalatal sutural opening between the two groups.

Table 15. Results of the Occlusal Radiographic Analysis Survey

	Rapid palatal Expander		Nickel titanium expander	
Evaluator	YES	NO	YES	NO
1	9	0	9	3
2	9	0	9	3
3	9	0	12	0
4	9	0	11	1
Total	36	0	41	7

B. DISCUSSION

1. LIMITATIONS OF STUDY.

a. Methodology. There are several sources of error present when evaluating molar rotation and molar tipping. With the methodology described in Chapter III, section D, molar rotation and tipping were initially evaluated by assessing changes in the angle of the intersecting wires (see Figure 15). This represents a one-dimensional view, of a three-dimensional object, with molar rotation, buccolingual tipping and mesiodistal tipping occurring simultaneously as expansion occurs. For this reason, as rotation of the molars occur, an apparent change in the angle of the intersecting wires when evaluating buccolingual molar tipping (as in Figure 15) also occurs when, in actuality, no tipping had occurred. Likewise, this same phenomena is also seen with buccolingual molar tipping causing an apparent change in molar rotation when, in reality, no rotations had occurred.

The effect of molar rotation on molar tipping was confirmed and reported in Figure 19 where it can be seen that small rotations of the molars produce small changes in the apparent tipping angle of the molars and a large amount of rotation causes a large change in the apparent tipping angle. As mentioned, this source of error is small when molar rotations and tipping changes are small. For example, in the RPE group patient #4 (Appendix E) had a total mesiobuccal rotation of the molars of 2 degrees and a total buccolingual tipping of 6 degrees. A 2 degree rotation contributes to an error of less than 0.5 degrees (Figure 19) when evaluating molar tipping. Likewise, a tipping of 6 degrees also produces an error of less than 0.5 degrees when evaluating molar rotation. Since the angular measurements are made only to the nearest degree, the error is insignificant. However, when rotations and tipping are large so is the potential error. For example

patient #22 (Appendix E) in the NITI expansion group had a total mesiobuccal rotation of the molars of 72 degrees. This large rotation produces an error of 61 degrees (see equation) when evaluating buccolingual molar tipping. Also, mesiodistal tipping of the molars (which wasn't evaluated in this study) can introduce a similar source of error when evaluating buccolingual tipping of the molars. This is particularly true in cases where there is a large amount of molar rotation, such as in patient #22.

Because the buccolingual tipping of the molars was relatively small (mean of 4 degrees for the RPE group and mean of 12 degrees for the NITI group), the error produced from tipping would also be small when evaluating molar rotation. For this reason, no correction was made to the observed rotations of the molars. However, the observed molar rotations tended to be large especially for the NITI group (mean molar rotation of 27 degrees with a maximum observed rotation of 72 degrees for patient #22). These relatively large rotations would have the potential to cause large errors when evaluating the buccolingual tipping of the molars, thereby, producing misleading results.

To help minimize the effect of molar rotation on molar tipping, buccolingual molar tipping was evaluated using the method as seen in Figure 17. By placing the wires perpendicular to the base of the cast and over the central fossa (approximating the center of rotation) of the maxillary first molar, any rotation of the molars would have little effect on the buccolingual tipping of the wires. This would, thereby, minimize the error produced by molar rotations when evaluating buccolingual tipping of the molars. For this reason, molar tipping data used for statistical comparison was evaluated using this method (Figure 17).

b. Sample. Due to incomplete appliance activation information in the NITI expansion and RPE groups, a statistical comparison between the two groups was judged impractical. In the RPE group, the amount of activation of the appliance, i.e. the number of turns of the screw, was not recorded in all cases. This made it impossible to determine how much the RPE appliance was activated in these cases.

Similarly, in the NITI expansion group the activation of the appliance was determined by measuring from the gingival margin of the lingual groove of the first molar to the gingival margin of the lingual groove of the opposite first molar and adding 3-4 mm. However, since the NITI expander is available in only eight sizes, some expanders may have been activated more or less than the recommended 3-4 mm. This made the activation of the NITI expander extremely subjective with the true amount of activation almost impossible to record.

Because it is not known how much the NITI expansion and RPE appliances were activated and because it's possible that there could have been a significant difference in the amount of activation of the expanders, statistical comparison of the two groups was not possible.

2. EFFECTS OF PALATAL EXPANSION.

a. Intermolar width change. Intermolar width change which is a reflection of the total amount of expansion produced by the expansion appliances was found to be significantly increased in both the NITI (6.26 mm) and RPE (4.76 mm) groups. Similar results were also found in the literature with both slow expansion and rapid expansion studies reporting significant increases in intermolar width.[22,25,39,41,43] The 8 out of 12 patients in the RPE group and the 11 out 13 patients in the NITI group that presented with posterior crossbites, all had their crossbites corrected following expansion. Interestingly, the amount of intermolar width increase in the NITI expansion group (6.26 mm) was greater than the 3 to 4 mm of recommended activation. This disparity in the amount of activation and the overall amount of intermolar width increase produced could be an indication that the true amount of activation of the appliance is greater than the 3 to 4 mm that the manufacturer recommends. Since the prefabricated NITI expander came in only 8 sizes (26mm, 29mm, 32mm, 35mm, 38mm, 41mm, 44mm, and 48mm), intermolar width measurements that are between appliance sizes could prompt the operator to choose the larger size resulting in the observed disparity.

b. Palatal width change. Palatal width change, which is a measurement of the amount of separation of the midpalatal suture, increased significantly in both the RPE (mean increase of 1.41 mm) and NITI (mean increase of 0.99 mm) expansion groups with more midpalatal sutural separation occurring in the RPE group. Similarly, when comparing the ratio of palatal width change to intermolar width change (percentage of skeletal expansion) for the RPE group and the NITI group, the RPE group demonstrated a greater percentage of skeletal expansion (28%) than did the NITI expansion group (16%).

This finding indicates that separation of the midpalatal suture contributes more to the overall expansion when using rapid palatal expansion appliance than it does when using nickel titanium palatal expansion appliance. Similar results were found in the literature with RPE studies reporting the percentage of skeletal expansion ranging from 40% - 58%[1,25,37,40] and slow expansion studies reporting ranges from 16% - 64%.[1,2,41,43,45]

c. <u>Alveolar tipping.</u> Both the RPE group and NITI expansion groups demonstrated significant buccal tipping of the alveolar process of 5.08 degrees and 6.61 degrees, respectively. The changes observed agree with the literature where it is reported that buccal tipping of the alveolar process during expansion results from an initial lateral bending of the alveolus[5,10] followed by a triangular separation of the maxillary halves with the apex located near the frontomaxillary suture and the base located near the alveolar region.[4,5,10,25]

d. <u>Molar rotation.</u> Because RPE appliances are rigid and are fabricated from pretreatment dental casts, it is expected that during expansion there would be very little if any rotations of the molars. This was confirmed by the present study, which demonstrated a statistically insignificant mean mesiobuccal rotation of the molars of 1.58 degrees in the RPE group. On the other hand, NITI expansion appliances are flexible and designed to cause mesiobuccal rotation of a molar that is mesiolingually rotated. This capability of NITI expansion appliances was also confirmed in this study with the mean mesiobuccal rotation of the molars being a statistically significant 26.61 degrees.

e. <u>Molar tipping</u>. Similarly, both expansion groups also showed significant increases in buccal molar tipping. The RPE and NITI expansion groups had a buccal molar tipping of 6.08 degrees and 11.69 degrees, respectively. The NITI expansion group

produced almost twice as much buccal molar tipping than the RPE group. Review of the literature indicates similar results, with Hicks[3] and Cotton[2] reporting 1.5 – 24 degrees and 2 – 17 degrees, respectively, of buccal molar tipping in a slow palatal expansion sample. Herold[57] concluded that minimal buccal tipping of the molars occurs with rapid expansion and that more buccal tipping is seen with slow expansion.

f. Palatal depth changes. The RPE group and NITI group demonstrated statistically insignificant changes in palatal depth of –0.07 mm and –0.04 mm, respectively. Palatal depth changes resulting from expansion have been reported to occur from a lowering of the palatal shelves of the maxilla[5] or from changes in dentoalveolar height.[1,34] Previous studies on palatal depth changes show some variability. Haas[5] reported observing a decrease in palatal depth due to a lowering of the palatal shelves following expansion, whereas, Ladner[1] demonstrated an increase in palatal depth in both rapid and slow palatal expansion, which they attributed to eruption of the dentition. However, Ladner evaluated palatal depth changes following expansion and full fixed appliance therapy. This may have resulted in growth and orthodontic therapy having an effect on eruption of the dentition. Other studies have shown no significant changes in palatal depth following expansion.[39] In the present study, if an increase in dentoalveolar height and a lowering of the palatal shelves had occurred, they were offset by each other resulting in no significant changes in palatal depth.

3. FACTORS RESPONSIBLE FOR PALATAL EXPANSION. In an evaluation of what factors might be most responsible for contributing to the overall amount of expansion (intermolar width change), a Stepwise Multiple Regression Analysis

and a Matrix of Pearson Correlation Analysis was performed. Both analysis revealed more unexplained variation in the NITI expansion group than in the RPE group.

a. RPE group. Through a regression analysis, alveolar tipping, palatal width change, and molar tipping were all found to be significant contributors to the multiple regression model, explaining 82% of the variability in the overall amount of expansion in the RPE group. Alveolar tipping was found to have the strongest relationship with intermolar width change, followed by palatal width change and molar tipping. This left only 18% of the variability in intermolar width change unexplained in the RPE group. Similar results were also found among correlations in the RPE group. Intermolar width change had significant positive correlations with alveolar tipping and palatal width change of r = 0.67 and r = 0.62, respectively. This suggests that as the total amount of expansion increases, so does midpalatal suture separation and buccal tipping of the alveolus. Although molar tipping was found to be a significant contributor to explaining intermolar width change in the regression analysis, the two were not significantly correlated (r = 0.42) using the Matrix of Pearson Correlation Coefficient Analysis.

b. NITI expansion group. In comparison, much more variability in explaining intermolar width change was observed in the NITI group with the only predictor meeting the 0.250 level of significance for inclusion into the regression model being palatal width change. Even so, palatal width change only had a significant level of contribution to the overall amount of expansion of p = 0.1771. This left 84% of the contributing factors to intermolar width change unexplained, with palatal width increase only accounting for 16% of the variability. Similarly, the overall correlations in the NITI group were also found to be low with palatal width change, alveolar tipping, and molar tipping not being

significantly correlated with intermolar width change. Even though palatal width increase had a positive correlation with intermolar width change ($r = 0.40$), the correlation was found to be insignificant ($p = 0.1771$). The only significant correlation found in the NITI group was between palatal width change and palatal depth change. This was a negative correlation, indicating that as the midpalatal suture separates or increases during expansion, the palatal depth decreases. Overall, this data suggests that there are no consistent factors responsible for the total amount of expansion in the NITI group. For example, palatal width increase may account for expansion in one patient but in another patient it may be molar tipping that is most responsible for expansion.

c. Age. It has been proposed that age plays an important role in achievement of palatal expansion. Most authors reported observing a decrease in the amount of skeletal expansion with an increase in the patient's age.[1-3,23,25,38,43] However, only one study reported a statistically significant remote negative correlation between age and skeletal expansion,[40] while other studies found no statistically significant correlations.[1,43] In the present study, age was not found to have influence in explaining the total amount of expansion in the regression model nor was age found to be correlated with any dental (molar tipping) or skeletal (mid palatal suture separation, alveolar tipping) components of expansion in either the NITI expansion or RPE group. These results suggest that age is not an important factor in determining the proportion of dental and skeletal components of expansion.

d. Treatment time. Likewise, the total treatment time (active expansion plus retention) was also found not to have an influence on palatal expansion. Results from the Matrix of Pearson Correlation of Coefficient Analysis revealed no significant correlation

between the length of treatment and palatal width change, intermolar width change, palatal depth change, alveolar tipping, molar rotation, and molar tipping in either the NITI expansion or RPE group.

4. RADIOGRAPHIC CHANGES OF THE MIDALATAL SUTURE.

Radiographic analysis of midpalatal suture separation revealed a statistically significant difference between the RPE group and NITI expansion group ($p = 0.017$). The RPE group demonstrated radiographic opening of the midpalatal suture 100% of the time with the NITI group demonstrating opening of the midpalatal suture 85.42% of the time. Individual evaluator variation was observed in the NITI expansion group with evaluator 1 and 2 reporting radiographic sutural opening in 9 out of 12 patients, evaluator 3 reporting sutural opening in 12 out of 12 patients, and evaluator 4 reporting opening in 11 out of 12 patients. This could be an indication that NITI expansion possibly produces a less obvious radiographic separation of the midpalatal suture when compared to RPE. One possible explanation for the differences observed may be that because NITI expansion appliances produce slow continuous forces, radiographs taken after two weeks may not provide enough time for the appliances to fully express their capabilities. Another possible reason may be due to physiologic sutural adjustment occurring, leading to bony deposition as expansion occurs.[7,8] Other radiographic studies involving slow expansion reported similar findings with evidence of midpalatal suture separation ranging from 50 – 80 percent of patients.[41,42]

CHAPTER V

SUMMARY AND CONCLUSIONS

A. SUMMARY

The purpose of this study was to evaluate and compare the maxillary dental and skeletal changes produced by a nickel titanium palatal expansion appliance to the dental and skeletal changes produced by a rapid palatal expansion appliance. Twenty five palatal expansion patients (12 RPE and 13 NITI) had orthodontic study models taken prior to expansion and at the end of the retention period following expansion. These pre and posttreatment study models were analyzed for changes in intermolar width, palatal width, palatal depth, alveolar tipping, molar tipping, and molar rotation. Also, occlusal radiographs taken prior to expansion and after 2 weeks following the start of expansion, were evaluated by 4 part time orthodontic faculty for evidence of midpalatal suture separation. The following results were found:

1. Molar rotation affects the apparent molar tipping angle and vice versa when using the methodology described. The exact effect of molar rotation (β) on the apparent molar tipping angle (δ) can be computed using the equation:

$$\delta = 2\left[\tan^{-1}\left(0.4142\sqrt{1+(\tan\beta)^2}\right)\right]$$

2. Statistically significant increases were found in intermolar width, palatal width, buccal tipping of the alveolus, and buccal tipping of the molars in both groups. No statistically significant changes in palatal depth were found for either group. The

NITI group produced a statistically significant mesiobuccal rotation of the molars, whereas, the RPE group did not.

3. More skeletal expansion was observed in the RPE group, whereas, the NITI group demonstrated more buccal molar tipping and more mesiobuccal molar rotation.
4. A statistically significant difference was found in radiographic evidence of midpalatal sutural separation with the RPE group demonstrating more evidence of an opening of the midpalatal suture.
5. In the RPE group, a statistically significant positive correlation was found between intermolar width change and palatal width change, intermolar width change and buccal tipping of the alveolus, and between mesiobuccal rotation of the molars and palatal width change. A statistically significant negative correlation was found between buccal tipping of the alveolus and palatal depth change. In the NITI group, the only statistically significant correlation was a negative correlation between palatal depth change and palatal width change.
6. Multiple regression analysis found alveolar tipping, palatal width change, and molar tipping to be statistically significant factors in explaining the increase in the overall amount of expansion in the RPE group. However, no statistically significant, consistent factors seem to be responsible in explaining the increase in expansion in the NITI group.

B. CONCLUSION

From this study, examining the effects of nickel titanium and rapid palatal expansion appliances, it can be concluded that:

1. Both NITI expansion and RPE expansion appliance are clinically capable of expanding the maxilla and correcting posterior crossbites.
2. More skeletal expansion can be expected using RPE appliances with more buccal tipping of the molars expected using NITI expansion appliances.
3. Increases in midpalatal sutural separation, buccal tipping of the alveolus, and buccal tipping of the molars occur in both groups following expansion. These three changes were important factors in explaining the increase in intermolar width in the RPE group. However, a much greater unexplained variability in intermolar width increase was present in the NITI group with midpalatal sutural separation, buccal tipping of the alveolus, and buccal molar tipping not being significantly related to intermolar width increase.
4. The NITI expansion appliances have the ability to correct mesiolingually rotated molars, whereas, the RPE appliance do not.
5. Palatal depth does not change following expansion with either the NITI or RPE appliance, suggesting that dentoalveolar height remains unchanged.
6. Radiographic evidence of separation of the midpalatal suture taken two weeks after insertion and activation of the appliances is less obvious in the NITI group than in the RPE group.

7. Age did not have an influence on any dental or skeletal changes seen with either the NITI expansion or RPE appliances.

It is recommended for future investigations comparing RPE and NITI expansion appliances that a larger sample size of patients be evaluated, thus increasing the statistical power of the results. Also, a better match of the two sample groups needs to be accomplished. Factors that need to be considered for comparison include the age, gender and dental development of the patient, the amount of appliance activation, the presence of posterior crossbites, and the length of treatment.

When evaluating occlusal radiographs it is suggested that a positioning device be constructed to ensure that the radiographs are taken at exact same position. Also, the radiographs should possibly be taken for a longer period of time. For example, every two weeks for 3 months rather than just the one, two week evaluation done in this study.

Since movement of the teeth (rotation, tipping, etc.) occur in three dimensions and affect each other, it is recommended that a method be devised for evaluating molar rotation and tipping in three dimensions rather than just the one-dimensional evaluation done in this study. This could possibly include the use of some type of digital analysis.

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APPENDIX A

IRB consent and assent forms

ROBERT C. BYRD
HEALTH SCIENCES CENTER
OF WEST VIRGINIA UNIVERSITY

School of Dentistry Department of Orthodontics

PARENTAL or GUARDIAN CONSENT FORM

A comparison of skeletal and dental changes between rapid palatal expansion and nickel titanium palatal expansion

Introduction. I, ________________________, have been asked to allow my child ______________________ to participate in this study. Dr. __________________ has explained the study to me.

Purposes of the Study. The purpose is to learn more about the specific effects of a palatal expansion appliance.

Description of Procedures. This study will be performed at West Virginia University orthodontic department. My child. along with approximately forty other children, will have his/her palate expanded with one of two commercially used expansion techniques (rapid palatal expansion or nickel titanium palatal expansion).

Risks and Discomforts. Other than routine risks and discomforts associated with orthodontic treatment. which have been explained to me. there are no known or expected addition risks or discomforts from participating in this study. Participation in this study will not affect my child's orthodontic treatment plan.

Benefits. I understand that this study may not be of direct benefit to my child, but may benefit generalizable knowledge.

Financial Considerations. No additional costs are associated with participation in this study other than regular orthodontic treatment fees. I understand that if my child is injured as a result of this study, compensation for my injuries will not voluntarily be provided by the investigator. West Virginia University, or other associated organizations and corporations.

Alternatives. Nonparticipation in this study will not alter nor affect my child's orthodontic treatment. Treatment alternatives, including no treatment. along with associated risks and benefits have been explained to me.

Contact Persons. For more information about this research, I can contact Dr. Christopher Ciambotti at 304-293-5217. For information regarding my child's rights as a research subject, I may contact the Executive Secretary of the Institutional Review Board at 293-7073.

Confidentiality. I understand that any information obtained as a result of my child's participation in this research will be kept as confidential as legally possible. I understand that these research records, just like hospital records, may be subpoenaed by court order or may be inspected by federal regulatory authorities. In any publications that result from this research, neither my name nor that of my child nor any information from which we might be identified will be published without my consent.

Voluntary Participation. Participation in this study is voluntary. I understand that I may withdraw my child from this study at any time. Refusal to participate or withdrawal will involve no penalty or loss of benefits for me or my child. I have been given the opportunity to ask questions about the research, and I have received answers concerning areas I did not understand. Upon signing this form, I will receive a copy.

I willingly consent to my child's participation in this study.

WEST VIRGINIA UNIVERSITY
Institution Review Board for the Protection of Human Research Subjects

APR 1 3 1998
APPROVED
X M. J. Frame
EXPIRES 4-13-99
H.S. # 13965

______________________ __________
Signature of Parent of Guardian Date

______________________ __________
Signature of Investigator Date

ROBERT C. BYRD
HEALTH SCIENCES CENTER
OF WEST VIRGINIA UNIVERSITY

School of Dentistry

Department of Orthodontics

ASSENT FORM

A comparison of skeletal and dental changes between rapid palatal expansion and nickel titanium palatal expansion

Introduction. I, ______________________________, have been asked to participate in this research study, which has been explained to me by Dr. ______________________.

Purposes of the Study. I have been told that the purpose of this study is to learn more about the specific effects of widening the upper jaw.

Description of Procedures. This study will be performed at West Virginia University orthodontic department. I will have my upper jaw widened with one of two commercially used expansion techniques (rapid palatal expansion or nickel titanium palatal expansion).

Risks and Discomforts. Other than routine risks and discomforts associated with orthodontic treatment, which have been explained to me, there are no known or expected addition risks or discomforts from participating in this study. Participation in this study will not affect my orthodontic treatment plan.

Benefits. I understand that this study may not help me, but society may benefit from the results of this study.

Confidentiality. I have been promised that anything that they learn about me is this study will be kept as secret as possible.

Voluntary Participation. I have been told that I do not have to do this. No one will be mad at me if I refuse to do this or if I decide to quit. I have been allowed to ask questions about the research, and all of my questions were answered. I will receive a copy of this form after I sign it.

I willingly agree to be in this study.

_________________________ Signature of Subject

____________ Date

_________________________ Signature of Investigator

____________ Date

WEST VIRGINIA UNIVERSITY
Institution Review Board for the
Protection of Human Research Subjects

APR 1 3 1998
APPROVED
X M. J. Quinn
EXPIRES 4-13-99
H.S. # 13465

1076 Health Sciences North PO Box 9480 Morgantown WV 26506-9480 Telephone 304 293-5217 FAX 304 293-2859

APPENDIX B

Operational instructions for Arndt Memory Expander

Arndt Memory Expander

Instructions

1. Appliance selection

a. Measure from the maxillary first molar lingual groove at the gingiva to the opposite lingual groove and add 3 or 4 mm to that number.

b. The appliance is manufactured in 8 sizes in 3 mm increments.

2. Chairside procedure

a. Select and fit bands containing lingual sheaths for the maxillary first molars.

b. While the bands are temporarily on the teeth fit and adjust the anterior arms of the Arndt Memory Expander as needed.

c. Remove the bands and pumice the teeth to be banded.

d. Tie the bands to the Arndt Memory Expander with stainless steel ligature wire.

e. Isolate and dry the teeth while the assistant fills the bands with cement.

f. Just before placement, spray the two nickel titanium wire loops with refrigerant spray.

g. With the nickel titanium wires chilled, compress and cement the appliance.

APPENDIX C

Patient information sheet

West Virginia University
Department of Orthodontics

Patient information sheet

Patient name:		Patient #	DOB:
Appliance type:		Operator:	
Crossbite:	Unilateral	Bilateral	None

	Rapid Palatal Expansion	**Niti Expansion**
Appliance type		NiTi Memory Expander
Date of initial occlusal x-ray		
Date of initial impressions		
Date of insertion		
Date of 2 week occlusal x-ray		
Date of final impressions		
Date of appliance removal		
Total length of treatment		

	Date	Phase of treatment (active or retention)	Reason (broken, loose band, etc.)
Failure of appliance			

APPENDIX D

Radiographic analysis survey

EVALUATOR ____________________

RADIOGRAPHIC ANALYSIS SURVEY

Is there any evidence of an increase in the mid palatal suture from radiograph A to radiograph B? Please check the appropriate box.

PATIENT #	YES	NO
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
16		
19		
20		
21		
22		
23		
24		

APPENDIX E

Derivation of the equation

Apparent Tipping due to Rotation

The methodology described in this study to evaluate molar tipping can introduce an error, resulting in an apparent dental tipping when non has actually occurred. If this apparent tipping is not accounted for, considerable misjudgments may be made regarding the tooth movement that actually occurred.

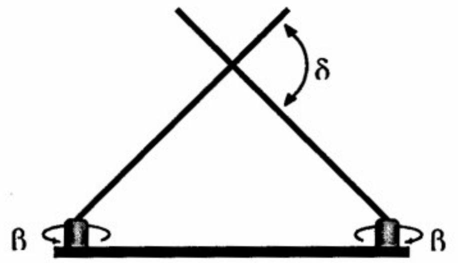


Figure E.1.

The methodology is schematically diagramed in Figure E.1, and is similar to the test setup presented earlier in this paper. As the molars rotate through an angle (β), the angle between the wires (δ) will appear to increase, when viewed from the sagittal, as shown in Figure E.1. This apparent increase is due to the geometry of the rotating wires and their intersection point.

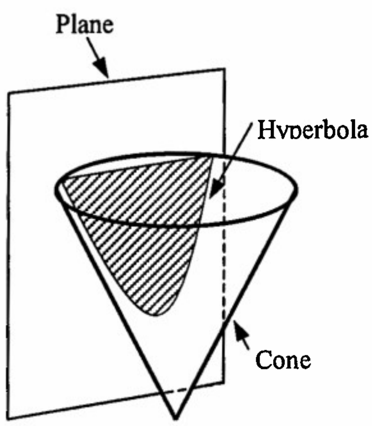


Figure E.2.

As the wires rotate, they sweep out the shape of a cone (see Figure E.2). Assuming the wires rotate at the same rate, their intersection point will always be located midway between the molars. This means the intersection point of the wires describes a curve that falls on a single plane. This plane also happens to be parallel to the cones' axis. From geometry, it is known that the intersection of a plane and a cone, where the plane is parallel to the cones axis, describes a curve called a hyperbola (see Figure E.2).

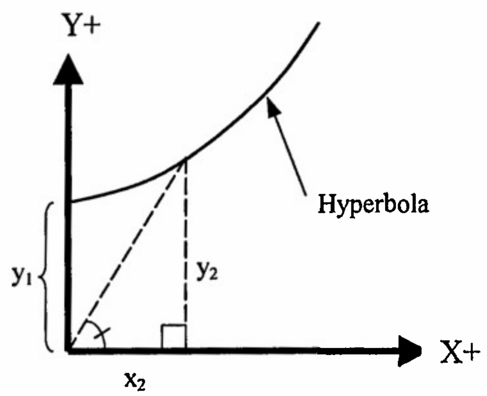


Figure E.3.

A lateral view is shown in Figure E.3. It can be been that as the wires rotate from their initial position y_1 along the hyperbolic path to the new intersection point (x_2, y_2), the intersection point moves in the positive y (Y+) direction. This vertical movement is what causes the apparent tipping mentioned above.

In order to quantify the apparent tipping, so that it may be properly accounted for, a mathematical expression must be derived relating the apparent tipping (δ) and the molar rotation (β).

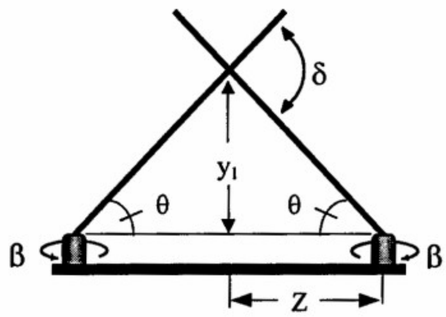


Figure E.4.

Referring to Figure E.4, it can be shown that the following is true:

$\delta = 2\theta$ (Eq. 1)

(δ_i) = initial angle = 45°

Z = ½ intermolar distance = 44.5 mm

$\theta = \tan^{-1}(y/z)$ (Eq. 2)

The equation for a hyperbola is given by the following:

$$\frac{y^2}{a^2} - \frac{x^2}{b^2} = 1 \qquad \text{(Eq.3)}$$

where: $a = y_1 = Z \tan(\delta_i/2)$
$b = Z$
x and y are as shown in Figure E.3

(Note: only Quadrant I, as shown in Figure E.3, is being considered).

Rearranging Eq.3 and solving for y yields:

$$y = a\sqrt{1+\frac{x^2}{b^2}} \qquad \text{(Eq. 4)}$$

Substituting Eq.2 into Eq.1 yields:

$$\delta = 2\,(\tan^{-1}(y/z)) \qquad \text{(Eq. 5)}$$

Substituting Eq. 4 into Eq. 5 yields:

$$\delta = 2\left[\tan^{-1}\left(\frac{a}{z}\sqrt{1+\frac{x^2}{b^2}}\right)\right] \qquad \text{(Eq. 6)}$$

From Figures E.3 and E.4:

$$x = z\,(\tan \beta) \qquad \text{(Eq. 7)}$$

Substituting for b and x in Eq. 6, using Eq. 7 for x and b = z yields:

$$\delta = 2\left[\tan^{-1}\left(\frac{a}{z}\sqrt{1+\frac{z^2(\tan\beta)^2}{z^2}}\right)\right] \qquad \text{(Eq. 8)}$$

Substituting for a in Eq.8 yields:

$$\delta = 2\left[\tan^{-1}\left(\frac{z\tan(\delta_i/2)}{z}\sqrt{1+\frac{z^2(\tan\beta)^2}{z^2}}\right)\right] \qquad \text{(Eq. 9)}$$

After expanding Eq. 9, z drops out of the equation (this means the equation is independent of the intermolar width):

$$\delta = 2\left[\tan^{-1}\left(\tan\left(\frac{\delta_i}{2}\right)\sqrt{1+(\tan\beta)^2}\right)\right] \qquad \text{(Eq. 10)}$$

Substituting for δ_i in Eq. 10 yields:

$$\delta = 2\left[\tan^{-1}\left(0.4142\sqrt{1+(\tan\beta)^2}\right)\right] \qquad \text{(Eq.11)}$$

Eq. 11 describes the apparent tipping δ for a given rotation β. As can be seen in Figure 19 in Chapter 4, for small rotations (less than 10°) the apparent tip is negligible. However, at larger rotations the apparent tip can be quite significant and needs to be accounted for.

APPENDIX F

RPE group raw data

RPE DATA

	PATIENT NUMBER						
	4	8	9	12	13	14	15
PALATAL WIDTH (mm)							
right	1.38	0.00	0.53	1.04	0.00	0.95	1.72
left	1.84	0.00	0.91	0.64	0.55	0.44	1.84
change	3.22	0.00	1.44	1.68	0.55	1.39	3.56
INTERMOLAR WIDTH (mm)							
pre	36.11	41.94	42.64	44.57	40.84	41.62	38.27
post	42.33	45.29	47.49	50.37	43.26	46.42	45.31
change	6.22	3.35	4.85	5.80	2.42	4.80	7.04
RATIO PWC/IMWC	0.52	0.00	0.30	0.29	0.23	0.29	0.49
ALVEOLAR TIP (deg)	9	9	3	0	3	5	13
PALATAL DEPTH (mm)							
pre	18.58	13.88	18.10	17.74	14.94	12.61	17.12
post	18.42	12.95	17.65	19.13	15.51	12.43	16.20
change	-0.16	-0.93	-0.45	1.39	0.57	-0.18	-0.92
MOLAR ROTATION (deg)							
pre	45	45	45	45	45	45	45
post	47	43	45	47	45	48	51
change	2	-2	0	2	0	3	6
MOLAR TIP 1 (deg)							
pre	45	45	45	45	45	45	45
post	51	47	50	50	47	52	48
change	6	2	5	5	2	7	3
MOLAR TIP 2 (deg)	10	0	2	-1	5	15	11
AGE (years)	13.17	9.25	13.67	14.25	11.83	7.33	9.33
TREATMENT TIME (days)	108	98	126	133	92	96	162
GENDER	M	M	F	M	F	F	M
CROSSBITE	Yes	No	No	Yes	No	Yes	Yes

RPE DATA (continued)

	PATIENT NUMBER				
	16	17	19	20	25
PALATAL WIDTH (mm)					
right	0.34	0.24	0.22	0.56	0.33
left	0.37	0.47	0.20	0.58	1.37
change	0.71	0.71	0.42	1.14	2.06
INTERMOLAR WIDTH (mm)					
pre	41.40	42.61	46.03	42.68	42.59
post	47.91	45.44	51.50	46.36	46.47
change	6.51	2.83	5.47	3.68	3.88
RATIO PWC/IMWC	0.11	0.25	0.08	0.31	0.53
ALVEOLAR TIP (deg)	12	-4	10	0	1
PALATAL DEPTH (mm)					
pre	20.72	15.29	20.40	15.11	13.15
post	20.49	14.74	19.03	14.38	14.53
change	-0.23	-0.55	-1.37	-0.65	1.38
MOLAR ROTATION (deg)					
pre	45	45	45	45	45
post	45	51	43	45	49
change	0	6	-2	0	4
MOLAR TIP 1 (deg)					
pre	45	45	45	45	45
post	55	46	52	52	43
change	10	1	7	7	-2
MOLAR TIP 2 (deg)	9	-1	12	13	-2
AGE (years)	14.92	8.5	14.08	10.67	6.67
TREATMENT TIME (days)	114	135	143	139	173
GENDER	M	F	F	F	M
CROSSBITE	Yes	Yes	Yes	No	Yes

APPENDIX G

NITI group raw data

NITI DATA

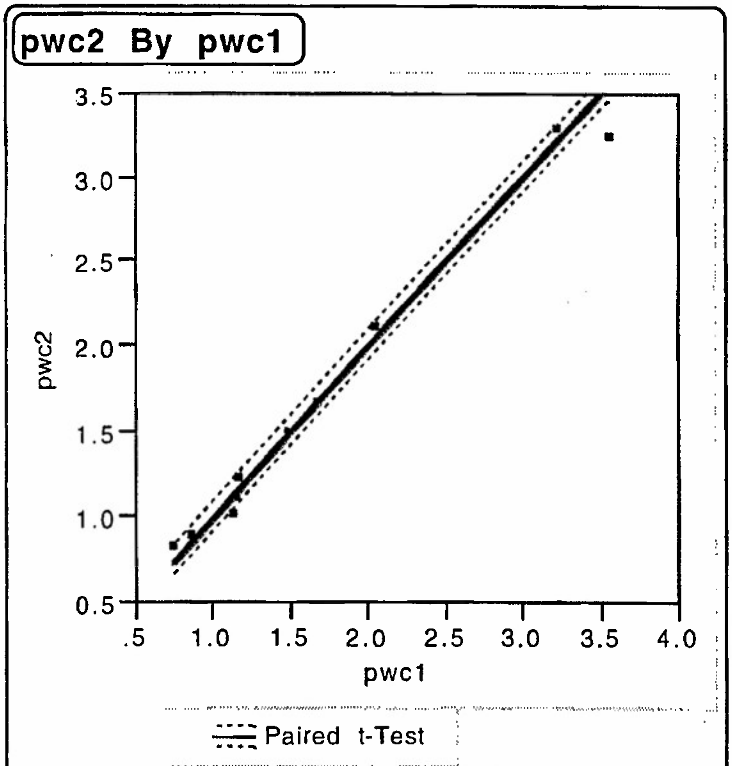
	PATIENT NUMBER						
	1	2	3	5	6	7	10
PALATAL WIDTH (mm)							
right	0.65	0.00	0.59	0.32	0.00	0.75	0.49
left	0.24	1.49	0.56	0.36	1.18	0.00	0.27
change	0.89	1.49	1.15	0.68	1.18	0.75	0.76
INTERMOLAR WIDTH (mm)							
pre	38.51	42.57	44.14	43.28	44.10	43.68	43.95
post	45.16	47.74	47.54	49.84	51.56	50.74	48.55
change	6.65	5.17	3.40	9.56	7.46	7.06	4.60
RATIO PWC/IMWC	0.13	0.29	0.34	0.10	0.16	0.11	0.17
ALVEOLAR TIP (deg)	2	6	3	5	6	11	9
PALATAL DEPTH (mm)							
pre	15.38	12.51	12.58	22.12	14.26	13.06	12.55
post	15.49	11.84	12.47	21.45	14.53	13.98	12.05
change	0.11	-0.68	-0.11	0.67	0.27	0.92	-0.50
MOLAR ROTATION (deg)							
pre	45	45	45	45	45	45	45
post	70	51	65	62	70	59	57
change	25	6	20	17	25	14	12
MOLAR TIP 1 (deg)							
pre	45	45	45	45	45	45	45
post	47	49	52	68	45	52	58
change	2	4	7	23	0	7	13
MOLAR TIP 2 (deg)	-2	8	7	26	-1	10	10
AGE (years)	10.08	8.92	10.33	13.66	7.42	7.25	5.83
TREATMENT TIME (days)	240	86	97	69	182	154	123
GENDER	M	F	M	F	F	F	F
CROSSBITE	Yes	Yes	Yes	Yes	Yes	Yes	Yes

NITI DATA (continued)

	PATIENT NUMBER					
	11	18	21	22	23	24
PALATAL WIDTH (mm)						
right	0.00	0.33	1.10	0.45	0.68	0.00
left	1.08	0.00	0.93	0.00	0.19	1.24
change	1.08	0.33	2.03		0.87	1.24
INTERMOLAR WIDTH (mm)						
pre	43.59	39.02	31.63	42.33	39.27	43.65
post	51.89	43.96	40.25	46.70	47.38	49.79
change	8.30	4.94	8.62	4.37	8.11	6.14
RATIO PWC/IMWC	0.13	0.07	0.24	0.10	0.11	0.20
ALVEOLAR TIP (deg)	10	1	7	11	3	12
PALATAL DEPTH (mm)						
pre	18.42	12.63	15.89	15.08	17.75	13.18
post	16.98	13.61	15.23	14.96	18.20	12.73
change	-1.44	0.98	-0.66	-0.12	0.45	-0.45
MOLAR ROTATION (deg)						
pre	45	45	45	45	45	45
post	81	72	71	117	81	75
change	36	27	26	72	36	30
MOLAR TIP 1 (deg)						
pre	45	45	45	45	45	45
post	61	61	61	62	67	52
change	16	16	16	17	22	7
MOLAR TIP 2 (deg)	12	26	17	-3	28	14
AGE (years)	11.08	7.75	4.92	10.5	12.42	12
TREATMENT TIME (days)	189	194	112	205	124	219
GENDER	F	F	M	F	F	F
CROSSBITE	Yes	Yes	Yes	No	Yes	No

APPENDIX H

Statistical analysis of measurement reproducibility

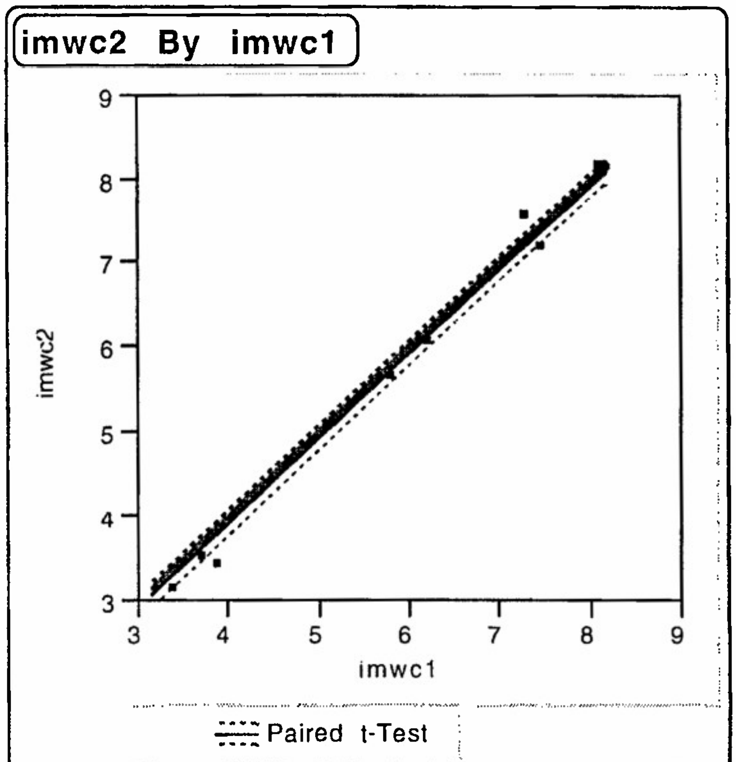


Paired t-Test

pwc1 - pwc2

Mean Difference	0.009	Prob > |t|	0.8191
Std Error	0.038223	Prob > t	0.4096
t-Ratio	0.23546	Prob < t	0.5904
DF	9		

Figure H.1. Paired *t*-test used to determine the reproducibility of the measurement of palatal width

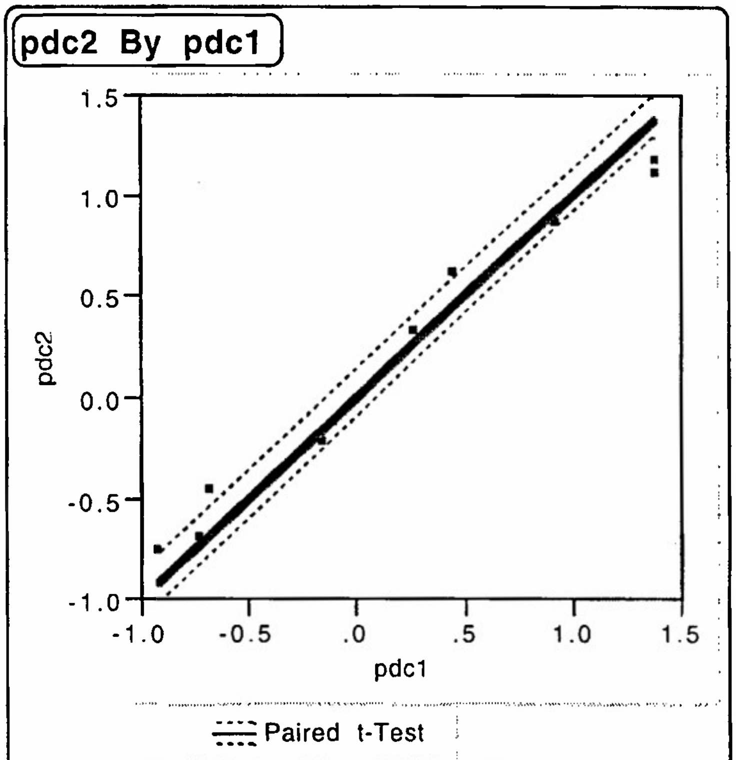


Paired t-Test

imwc1 - imwc2

Mean Difference	0.101	Prob > |t|	0.1390
Std Error	0.062226	Prob > t	0.0695
t-Ratio	1.623108	Prob < t	0.9305
DF	9		

Figure H.2. Paired *t*-test used to determine the reproducibility of the measurement of intermolar width

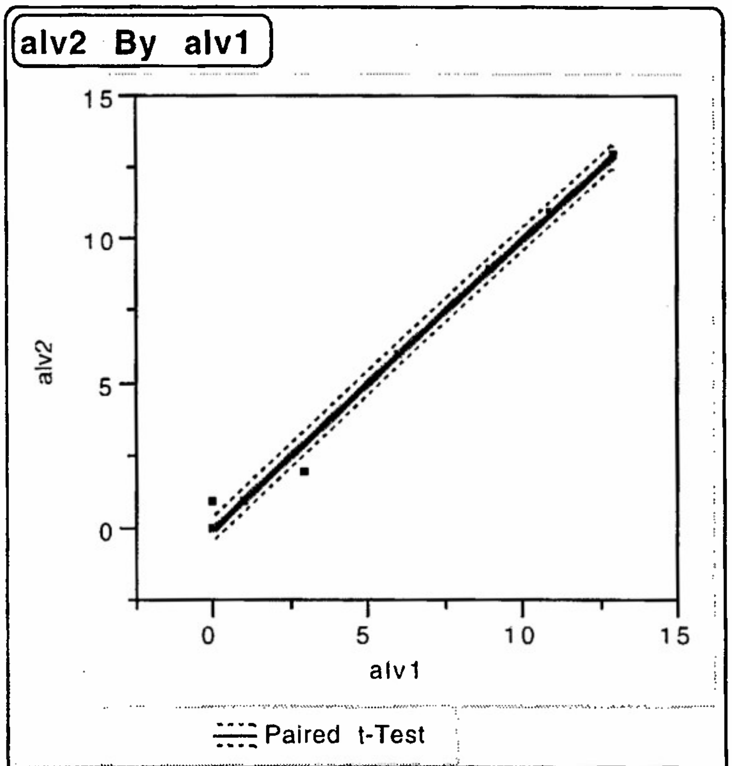


Paired t-Test

pdc1 - pdc2

Mean Difference	-0.017	Prob > |t|	0.7484
Std Error	0.051404	Prob > t	0.6258
t-Ratio	-0.33072	Prob < t	0.3742
DF	9		

Figure H.3. Paired *t*-test used to determine the reproducibility of the measurement of palatal depth

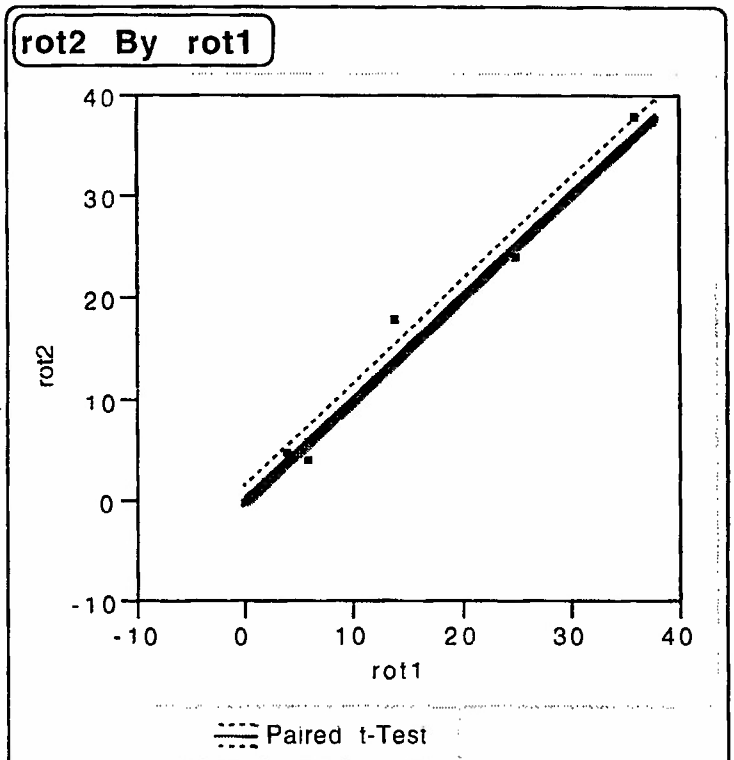


Paired t-Test

alv1 - alv2

Mean Difference	0.1	Prob > |t|	0.5911
Std Error	0.179505	Prob > t	0.2955
t-Ratio	0.557086	Prob < t	0.7045
DF	9		

Figure H.4. Paired t-test used to determine the reproducibility of the measurement of alveolar tipping

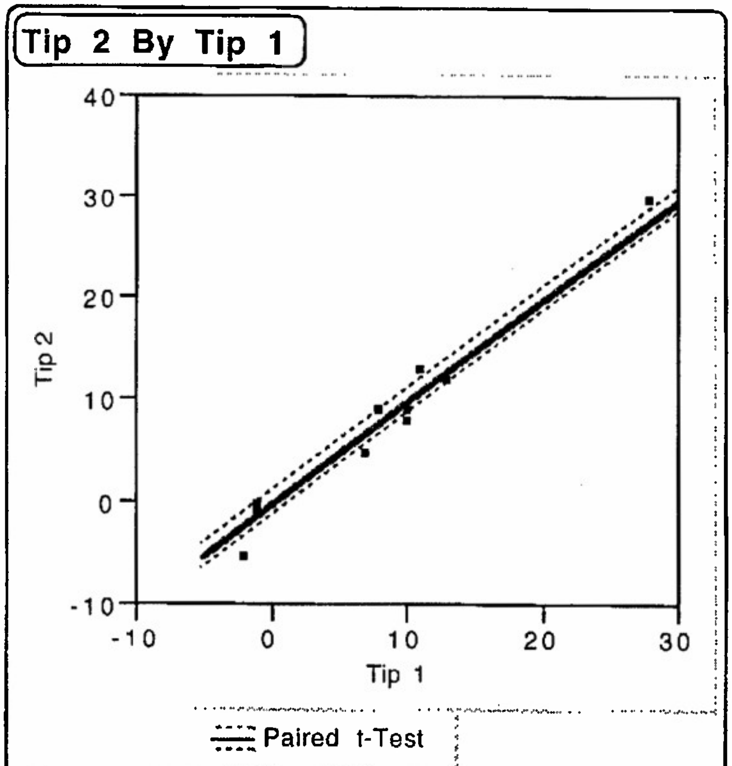


Paired t-Test

rot1 - rot2

Mean Difference	-0.4	Prob > ltl	0.4620
Std Error	0.520683	Prob > t	0.7690
t-Ratio	-0.76822	Prob < t	0.2310
DF	9		

Figure H.5. Paired *t*-test used to determine the reproducibility of the measurement of molar rotation



Paired t-Test

Tip 1 - Tip 2

Mean Difference	0.3	Prob > |t|	0.6044
Std Error	0.558768	Prob > t	0.3022
t-Ratio	0.536895	Prob < t	0.6978
DF	9		

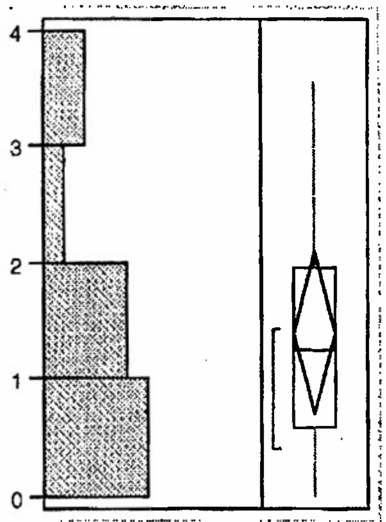
Figure H.6. Paired *t*-test used to determine the reproducibility of the measurement of alveolar tipping

APPENDIX I

Statistical analysis of RPE changes

RPE - Change t-tests

PWC



Quantiles

maximum	100.0%	3.5600
	99.5%	3.5600
	97.5%	3.5600
	90.0%	3.4580
quartile	75.0%	1.9650
median	50.0%	1.2650
quartile	25.0%	0.5900
	10.0%	0.1260
	2.5%	0.0000
	0.5%	0.0000
minimum	0.0%	0.0000

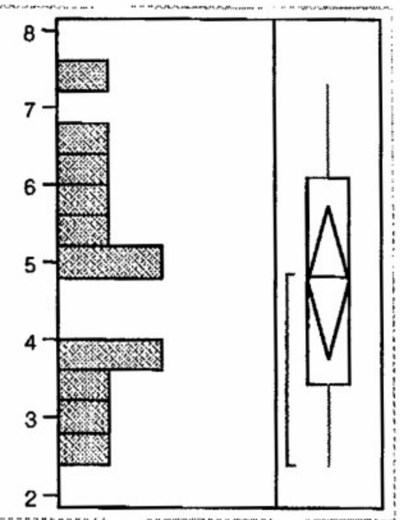
Moments

Mean	1.40667
Std Dev	1.09361
Std Error Mean	0.31570
Upper 95% Mean	2.10152
Lower 95% Mean	0.71182
N	12.00000
Sum Weights	12.00000

Test Mean=value

Hypothesized Value	0
Actual Estimate	1.40667
	t Test
Test Statistic	4.4557
Prob > |t|	0.0010
Prob > t	0.0005
Prob < t	0.9995

IMWC



Quantiles

maximum	100.0%	7.3100
	99.5%	7.3100
	97.5%	7.3100
	90.0%	7.0700
quartile	75.0%	6.1150
median	50.0%	4.8250
quartile	25.0%	3.4325
	10.0%	2.5430
	2.5%	2.4200
	0.5%	2.4200
minimum	0.0%	2.4200

Moments

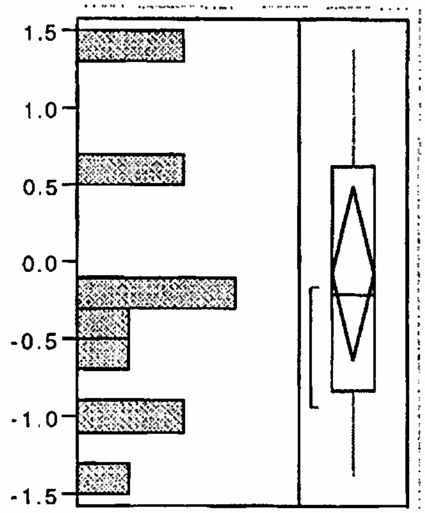
Mean	4.76000
Std Dev	1.54982
Std Error Mean	0.44739
Upper 95% Mean	5.74471
Lower 95% Mean	3.77529
N	12.00000
Sum Weights	12.00000

Test Mean=value

Hypothesized Value	0
Actual Estimate	4.76
	t Test
Test Statistic	10.6394
Prob > |t|	<.0001
Prob > t	<.0001
Prob < t	1.0000

Figure I.1. Paired *t*-test used to evaluate changes in palatal width and intermolar width in the RPE group

PDC



Quantiles

maximum	100.0%	1.3900
	99.5%	1.3900
	97.5%	1.3900
	90.0%	1.3870
quartile	75.0%	0.6300
median	50.0%	-0.2050
quartile	25.0%	-0.8275
	10.0%	-1.2380
	2.5%	-1.3700
	0.5%	-1.3700
minimum	0.0%	-1.3700

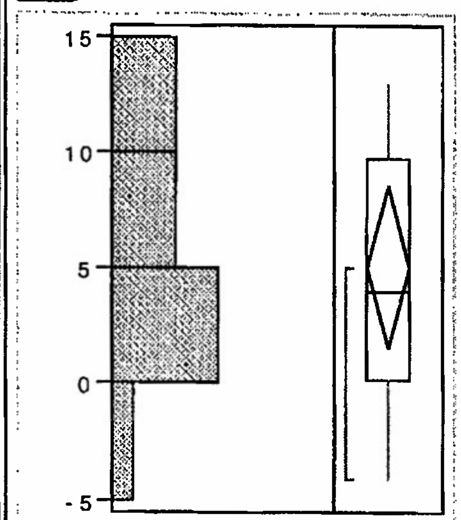
Moments

Mean	-0.06667
Std Dev	0.89110
Std Error Mean	0.25724
Upper 95% Mean	0.49951
Lower 95% Mean	-0.63285
N	12.00000
Sum Weights	12.00000

Test Mean=value

Hypothesized Value		0
Actual Estimate		-0.0667
	t Test	
Test Statistic	-0.2592	
Prob > |t|	0.8003	
Prob > t	0.5999	
Prob < t	0.4001	

AT



Quantiles

maximum	100.0%	13.000
	99.5%	13.000
	97.5%	13.000
	90.0%	12.700
quartile	75.0%	9.750
median	50.0%	4.000
quartile	25.0%	0.250
	10.0%	-2.800
	2.5%	-4.000
	0.5%	-4.000
minimum	0.0%	-4.000

Moments

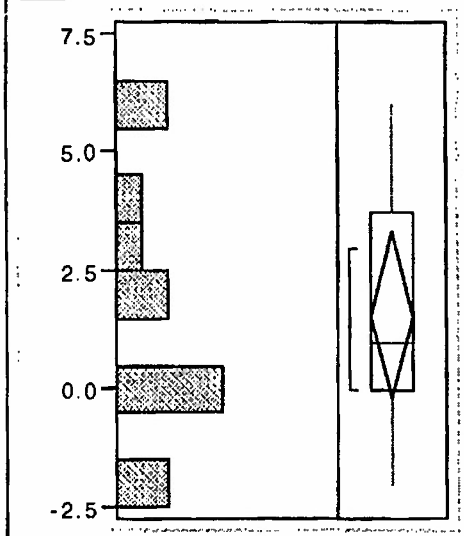
Mean	5.08333
Std Dev	5.43488
Std Error Mean	1.56891
Upper 95% Mean	8.53650
Lower 95% Mean	1.63016
N	12.00000
Sum Weights	12.00000

Test Mean=value

Hypothesized Value		0
Actual Estimate		5.08333
	t Test	
Test Statistic	3.2400	
Prob > |t|	0.0079	
Prob > t	0.0039	
Prob < t	0.9961	

Figure I.2. Paired *t*-test used to evaluate changes in palatal depth and alveolar tipping in the RPE group

MR



Quantiles

maximum	100.0%	6.0000
	99.5%	6.0000
	97.5%	6.0000
	90.0%	6.0000
quartile	75.0%	3.7500
median	50.0%	1.0000
quartile	25.0%	0.0000
	10.0%	-2.0000
	2.5%	-2.0000
	0.5%	-2.0000
minimum	0.0%	-2.0000

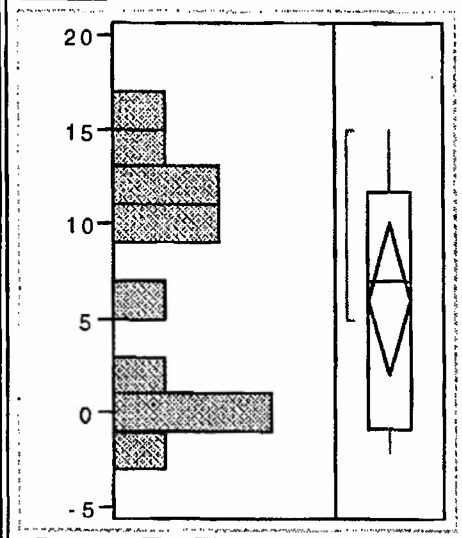
Moments

Mean	1.58333
Std Dev	2.74552
Std Error Mean	0.79256
Upper 95% Mean	3.32776
Lower 95% Mean	-0.16109
N	12.00000
Sum Weights	12.00000

Test Mean=value

Hypothesized Value	0
Actual Estimate	1.58333
	t Test
Test Statistic	1.9977
Prob > |t|	0.0711
Prob > t	0.0355
Prob < t	0.9645

MT 2



Quantiles

maximum	100.0%	15.000
	99.5%	15.000
	97.5%	15.000
	90.0%	14.400
quartile	75.0%	11.750
median	50.0%	7.000
quartile	25.0%	-0.750
	10.0%	-1.700
	2.5%	-2.000
	0.5%	-2.000
minimum	0.0%	-2.000

Moments

Mean	6.08333
Std Dev	6.25893
Std Error Mean	1.80680
Upper 95% Mean	10.06008
Lower 95% Mean	2.10658
N	12.00000
Sum Weights	12.00000

Test Mean=value

Hypothesized Value	0
Actual Estimate	6.08333
	t Test
Test Statistic	3.3669
Prob > |t|	0.0063
Prob > t	0.0031
Prob < t	0.9969

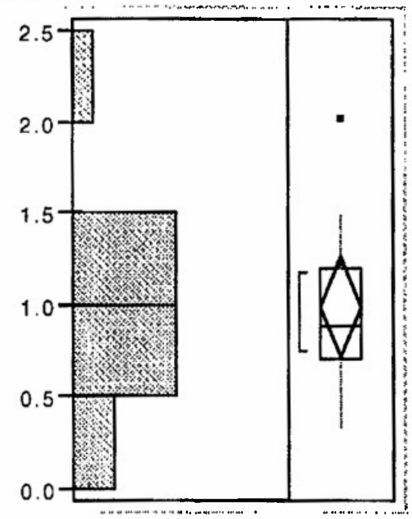
Figure I.3. Paired *t*-test used to evaluate changes in molar rotation and molar tipping in the RPE group

APPENDIX J

Statistical analysis of NITI changes

Niti - Change t-tests

PWC



Quantiles

maximum	100.0%	2.0300
	99.5%	2.0300
	97.5%	2.0300
	90.0%	1.8140
quartile	75.0%	1.2100
median	50.0%	0.8900
quartile	25.0%	0.7150
	10.0%	0.3780
	2.5%	0.3300
	0.5%	0.3300
minimum	0.0%	0.3300

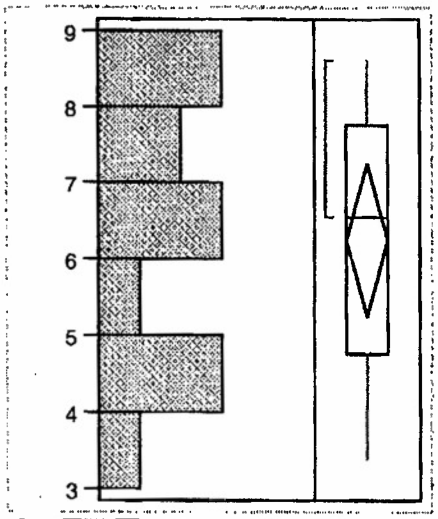
Moments

Mean	0.99231
Std Dev	0.44926
Std Error Mean	0.12460
Upper 95% Mean	1.26379
Lower 95% Mean	0.72082
N	13.00000
Sum Weights	13.00000

Test Mean=value

Hypothesized Value	0
Actual Estimate	0.99231
	t Test
Test Statistic	7.9638
Prob > |t|	<.0001
Prob > t	<.0001
Prob < t	1.0000

IMWC



Quantiles

maximum	100.0%	8.6200
	99.5%	8.6200
	97.5%	8.6200
	90.0%	8.4920
quartile	75.0%	7.7850
median	50.0%	6.5600
quartile	25.0%	4.7700
	10.0%	3.7880
	2.5%	3.4000
	0.5%	3.4000
minimum	0.0%	3.4000

Moments

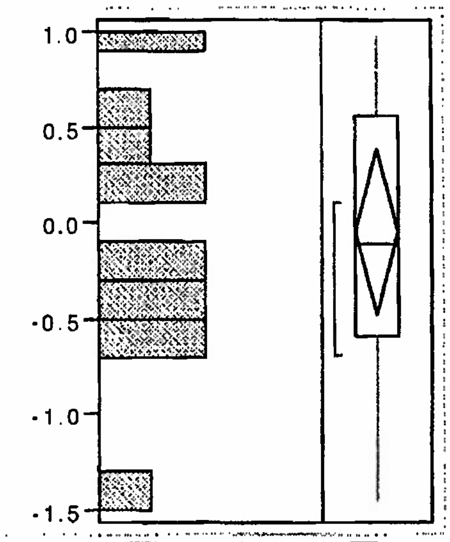
Mean	6.26000
Std Dev	1.65650
Std Error Mean	0.45943
Upper 95% Mean	7.26102
Lower 95% Mean	5.25898
N	13.00000
Sum Weights	13.00000

Test Mean=value

Hypothesized Value	0
Actual Estimate	6.26
	t Test
Test Statistic	13.6255
Prob > |t|	<.0001
Prob > t	<.0001
Prob < t	1.0000

Figure J.1. Paired *t*-test used to evaluate changes in palatal width and intermolar width in the NITI group

PDC



Quantiles

maximum	100.0%	0.9800
	99.5%	0.9800
	97.5%	0.9800
	90.0%	0.9560
quartile	75.0%	0.5600
median	50.0%	-0.1100
quartile	25.0%	-0.5800
	10.0%	-1.1360
	2.5%	-1.4400
	0.5%	-1.4400
minimum	0.0%	-1.4400

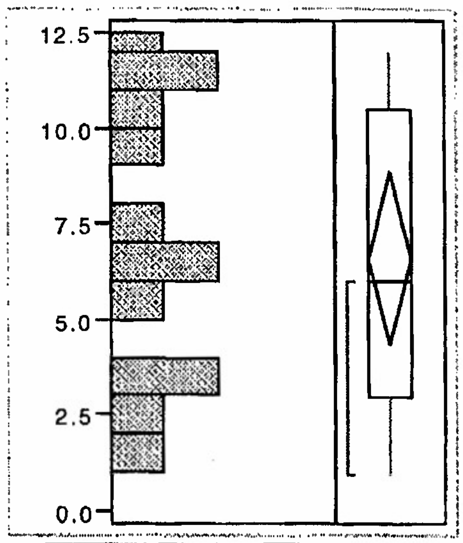
Moments

Mean	-0.04308
Std Dev	0.70532
Std Error Mean	0.19562
Upper 95% Mean	0.38314
Lower 95% Mean	-0.46930
N	13.00000
Sum Weights	13.00000

Test Mean=value

Hypothesized Value	0
Actual Estimate	-0.0431
	t Test
Test Statistic	-0.2202
Prob > |t|	0.8294
Prob > t	0.5853
Prob < t	0.4147

AT



Quantiles

maximum	100.0%	12.000
	99.5%	12.000
	97.5%	12.000
	90.0%	11.600
quartile	75.0%	10.500
median	50.0%	6.000
quartile	25.0%	3.000
	10.0%	1.400
	2.5%	1.000
	0.5%	1.000
minimum	0.0%	1.000

Moments

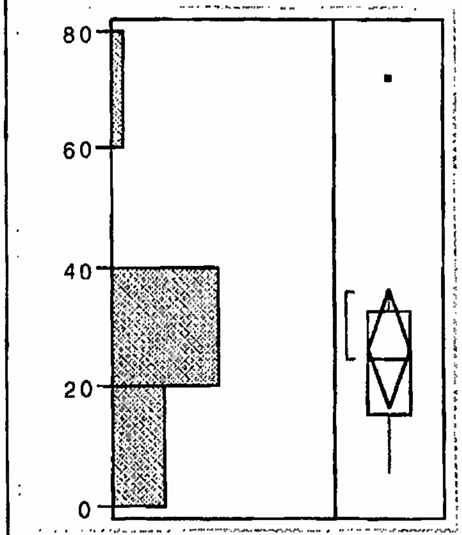
Mean	6.61538
Std Dev	3.73136
Std Error Mean	1.03489
Upper 95% Mean	8.87023
Lower 95% Mean	4.36054
N	13.00000
Sum Weights	13.00000

Test Mean=value

Hypothesized Value	0
Actual Estimate	6.61538
	t Test
Test Statistic	6.3923
Prob > |t|	<.0001
Prob > t	<.0001
Prob < t	1.0000

Figure J.2. Paired *t*-test used to evaluate changes in palatal depth and alveolar tipping in the NITI group

MR



Quantiles

maximum	100.0%	72.000
	99.5%	72.000
	97.5%	72.000
	90.0%	57.600
quartile	75.0%	33.000
median	50.0%	25.000
quartile	25.0%	15.500
	10.0%	8.400
	2.5%	6.000
	0.5%	6.000
minimum	0.0%	6.000

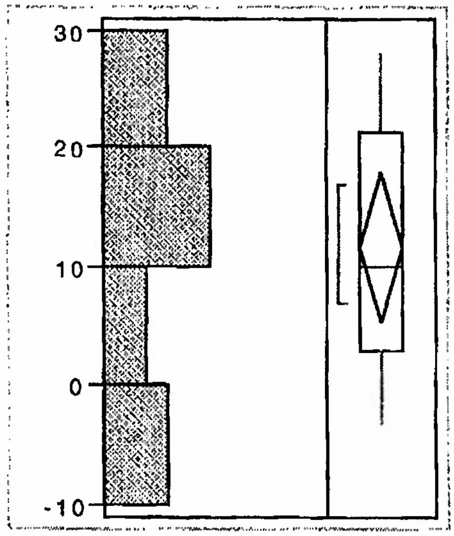
Moments

Mean	26.61538
Std Dev	16.29692
Std Error Mean	4.51995
Upper 95% Mean	36.46353
Lowor 95% Mean	16.76724
N	13.00000
Sum Weights	13.00000

Test Mean=value

Hypotheslzed Valuo	0
Actual Estimate	26.6154
	t Test
Test Statistic	5.8884
Prob > ltl	<.0001
Prob > t	<.0001
Prob < t	1.0000

MT 2



Quantiles

maxlmum	100.0%	28.000
	99.5%	28.000
	97.5%	28.000
	90.0%	27.200
quartile	75.0%	21.500
median	50.0%	10.000
quartile	25.0%	3.000
	10.0%	-2.600
	2.5%	-3.000
	0.5%	-3.000
minlmum	0.0%	-3.000

Moments

Mean	11.69231
Std Dev	10.46729
Std Error Mean	2.90310
Upper 95% Mean	18.01764
Lower 95% Mean	5.36698
N	13.00000
Sum Weights	13.00000

Test Mean=value

Hypothesized Value	0
Actual Estimate	11.6923
	t Test
Test Statistic	4.0275
Prob > ltl	0.0017
Prob > t	0.0008
Prob < t	0.9992

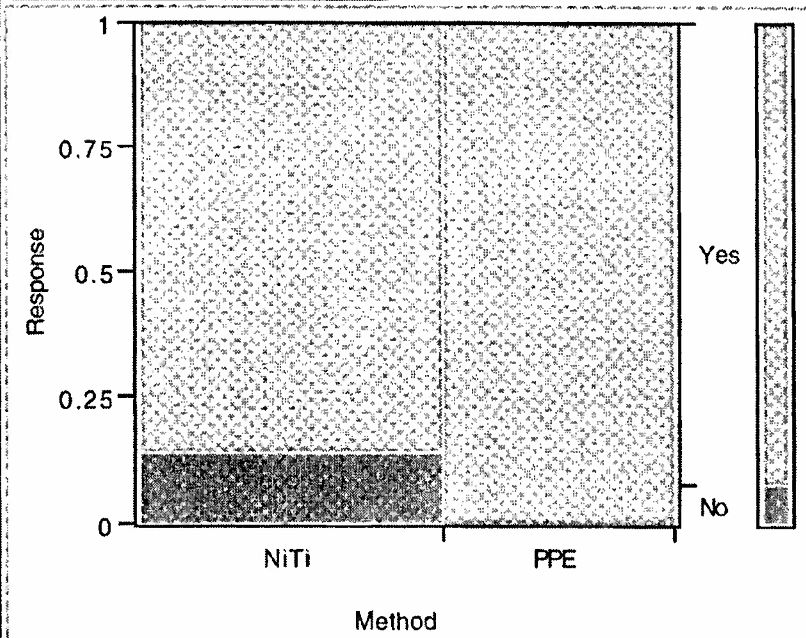
Figure J.3. Paired *t*-test used to evaluate changes in molar rotation and molar tipping in the NITI group

APPENDIX K

Statistical analysis of radiographic survey

Response By Method

CHI-SQUARE



Crosstabs

Method

Response	Count / Col %	NiTi	PPE	
	No	7 14.58	0 0.00	7
	Yes	41 85.42	36 100.00	77
		48	36	84

Tests

Source	DF	-LogLikelihood	RSquare (U)
Model	1	4.154400	0.1724
Error	82	19.939823	
C Total	83	24.094223	
Total Count	84		

Test	ChiSquare	Prob>ChiSq
Likelihood Ratio	8.309	0.0039
Pearson	5.727	0.0167

Fisher's Exact Test	Prob
Left	1.0000
Right	0.0163
2-Tail	0.0181

Cochran-Mantel-Haenszel Tests

APPENDIX L

Statistical analysis of correlations in the NITI group

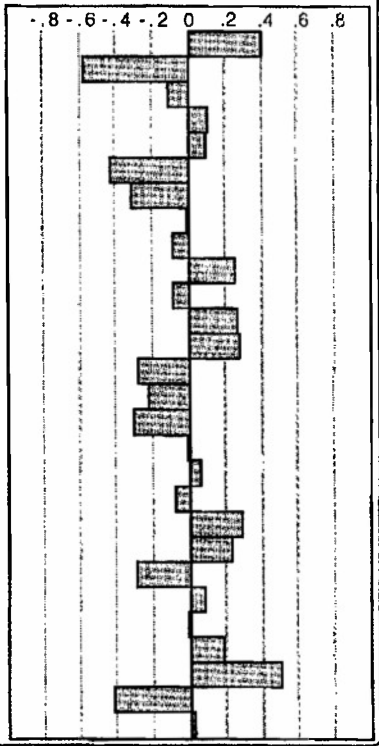
NITI Correlations

Correlations

Variable	PWC	IMWC	PDC	AT	MR	MT 2	AGE	LENGTH
PWC	1.0000	0.3987	-0.5770	0.1084	-0.3071	-0.0819	-0.2981	-0.2942
IMWC	0.3987	1.0000	-0.1060	0.0963	-0.0047	0.2622	-0.0102	0.0821
PDC	-0.5770	-0.1060	1.0000	-0.4213	-0.0876	0.2834	0.0627	-0.0099
AT	0.1084	0.0963	-0.4213	1.0000	0.2509	-0.2828	-0.0734	0.1849
MR	-0.3071	-0.0047	-0.0876	0.2509	1.0000	-0.2162	0.2888	0.5085
MT 2	-0.0819	0.2622	0.2834	-0.2828	-0.2162	1.0000	0.2293	-0.4193
AGE	-0.2981	-0.0102	0.0627	-0.0734	0.2888	0.2293	1.0000	0.0267
LENGTH	-0.2942	0.0821	-0.0099	0.1849	0.5085	-0.4193	0.0267	1.0000

Pairwise Correlations

Variable	by Variable	Correlation	Count	Signif Prob
IMWC	PWC	0.3987	13	0.1771
PDC	PWC	-0.5770	13	0.0390
PDC	IMWC	-0.1060	13	0.7304
AT	PWC	0.1084	13	0.7243
AT	IMWC	0.0963	13	0.7544
AT	PDC	-0.4213	13	0.1516
MR	PWC	-0.3071	13	0.3075
MR	IMWC	-0.0047	13	0.9878
MR	PDC	-0.0876	13	0.7759
MR	AT	0.2509	13	0.4084
MT 2	PWC	-0.0819	13	0.7903
MT 2	IMWC	0.2622	13	0.3869
MT 2	PDC	0.2834	13	0.3481
MT 2	AT	-0.2828	13	0.3492
MT 2	MR	-0.2162	13	0.4781
AGE	PWC	-0.2981	13	0.3226
AGE	IMWC	-0.0102	13	0.9737
AGE	PDC	0.0627	13	0.8388
AGE	AT	-0.0734	13	0.8117
AGE	MR	0.2888	13	0.3387
AGE	MT 2	0.2293	13	0.4510
LENGTH	PWC	-0.2942	13	0.3293
LENGTH	IMWC	0.0821	13	0.7898
LENGTH	PDC	-0.0099	13	0.9744
LENGTH	AT	0.1849	13	0.5453
LENGTH	MR	0.5085	13	0.0760
LENGTH	MT 2	-0.4193	13	0.1538
LENGTH	AGE	0.0267	13	0.9310



APPENDIX M

Statistical analysis of correlations in the RPE group

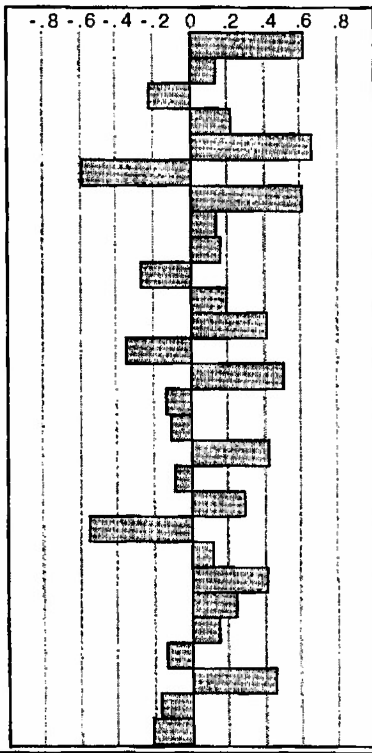
RPE Correlations

Correlations

Variable	PWC	IMWC	PDC	AT	MR	MT 2	AGE	LENGTH
PWC	1.0000	0.6196	0.1437	0.2189	0.6135	0.1978	-0.1046	0.4115
IMWC	0.6196	1.0000	-0.2261	0.6690	0.1436	0.4181	0.4245	0.2464
PDC	0.1437	-0.2261	1.0000	-0.5842	0.1667	-0.3466	-0.0902	0.1568
AT	0.2189	0.6690	-0.5842	1.0000	-0.2655	0.5022	0.2846	-0.1268
MR	0.6135	0.1436	0.1667	-0.2655	1.0000	-0.1301	-0.5470	0.4557
MT 2	0.1978	0.4181	-0.3466	0.5022	-0.1301	1.0000	0.1178	-0.1633
AGE	-0.1046	0.4245	-0.0902	0.2846	-0.5470	0.1178	1.0000	-0.2077
LENGTH	0.4115	0.2464	0.1568	-0.1268	0.4557	-0.1633	-0.2077	1.0000

Pairwise Correlations

Variable	by Variable	Correlation	Count	Signif Prob
IMWC	PWC	0.6196	12	0.0317
PDC	PWC	0.1437	12	0.6560
PDC	IMWC	-0.2261	12	0.4799
AT	PWC	0.2189	12	0.4942
AT	IMWC	0.6690	12	0.0173
AT	PDC	-0.5842	12	0.0461
MR	PWC	0.6135	12	0.0339
MR	IMWC	0.1436	12	0.6562
MR	PDC	0.1667	12	0.6045
MR	AT	-0.2655	12	0.4042
MT 2	PWC	0.1978	12	0.5377
MT 2	IMWC	0.4181	12	0.1762
MT 2	PDC	-0.3466	12	0.2697
MT 2	AT	0.5022	12	0.0961
MT 2	MR	-0.1301	12	0.6871
AGE	PWC	-0.1046	12	0.7463
AGE	IMWC	0.4245	12	0.1689
AGE	PDC	-0.0902	12	0.7805
AGE	AT	0.2846	12	0.3700
AGE	MR	-0.5470	12	0.0657
AGE	MT 2	0.1178	12	0.7154
LENGTH	PWC	0.4115	12	0.1839
LENGTH	IMWC	0.2464	12	0.4401
LENGTH	PDC	0.1568	12	0.6266
LENGTH	AT	-0.1268	12	0.6945
LENGTH	MR	0.4557	12	0.1365
LENGTH	MT 2	-0.1633	12	0.6120
LENGTH	AGE	-0.2077	12	0.5171



APPENDIX N

RPE stepwise multiple regression analysis

Response: IMWC RPE STEPWISE MULTIPLE REGRESSION ANALYSIS

Stepwise Regression Control

Prob to Enter	0.250	Enter All
Prob to Leave	0.250	
Direction	Mixed	Remove All

Go Stop Step Make Model

Current Estimates

SSE	DFE	MSE	RSquare	RSquare Adj	Cp	AIC
4.6307517	8	0.578844	0.8247	0.7590	3.938665	-3.42625

Lock	Entered	Parameter	Estimate	nDF	SS	"F Ratio"	"Prob>F"
☒	☒	Intercept	2.20529407	1	0	0.000	1.0000
☐	☒	PWC	0.81614449	1	8.008003	13.834	0.0059
☐	☒	AT	0.10529358	1	2.755593	4.761	0.0607
☐	☒	MT	0.19730271	1	3.752656	6.483	0.0344
☐	☐	AGE	•	1	0.547539	0.939	0.3649

Step History

Step	Parameter	Action	"Sig Prob"	Seq SS	RSquare	Cp	p
1	AT	Entered	0.0173	11.82691	0.4476	17.02	2
2	PWC	Entered	0.0296	6.211083	0.6827	8.372	3
3	MT	Entered	0.0344	3.752656	0.8247	3.9387	4

APPENDIX O

NITI stepwise multiple regression analysis

Response: IMWC NITI STEPWISE MULTIPLE REGRESSION ANALYSIS

Stepwise Regression Control

Prob to Enter 0.250
Prob to Leave 0.250
Direction Mixed

Enter All
Remove All
Go Stop Step Make Model

Current Estimates

SSE	DFE	MSE	RSquare	RSquare Adj	Cp	AIC
27.692426	11	2.517493	0.1590	0.0825	0.199628	13.83072

Lock	Entered	Parameter	Estimate	nDF	SS	"F Ratio"	"Prob>F"
☒	☒	Intercept	4.80105582	1	0	0.000	1.0000
☐	☒	PWC	1.47025382	1	5.235574	2.080	0.1771
☐	☐	AT	•	1	0.093665	0.034	0.8575
☐	☐	MT 2	•	1	2.881457	1.161	0.3065
☐	☐	AGE	•	1	0.426822	0.157	0.7007

Step History

Step	Parameter	Action	"Sig Prob"	Seq SS	RSquare	Cp	p
1	PWC	Entered	0.1771	5.235574	0.1590	0.1996	2

ABSTRACT

A Comparison of Dental and Skeletal Changes Between Rapid Palatal Expansion and Nickel Titanium Palatal Expansion

Expansion of the maxilla is used to correct skeletal and dental transverse discrepancies between the maxilla and mandible. These discrepancies are corrected through a combination of skeletal expansion (separation of the maxillary midpalatal suture) and dental expansion (lateral tipping of the maxillary posterior teeth). A recently introduced temperature-activated, nickel titanium (NITI) palatal expander is claimed to produce a light, continuous force which is capable of expanding the maxilla and correcting molar rotations. The skeletal and dental effects of the NITI expander on the maxilla have not been scientifically evaluated. The purpose of this study was to evaluate and compare the dental and skeletal changes produced by a NITI expander to the changes produced by a rapid palatal expansion (RPE) appliance.

25 patients (12 RPE, 13 NITI) had orthodontic study models taken before and after treatment. The models were evaluated via palatal contour tracings and photographs for changes in intermolar width, palatal width, palatal depth, alveolar tipping, molar tipping, and molar rotation. Data were analyzed using Paired *t*-tests, Pearson Correlation Coefficients, and a Stepwise Multiple Regression Analysis. Also occlusal radiographs, taken before and 2 weeks following insertion and activation of the appliances, were evaluated for evidence of separation of the midpalatal suture. The results were analyzed using a Chi-square test.

Both the RPE and NITI expansion appliances were able to produce significant increases in intermolar width, palatal width, alveolar tipping and molar tipping. No significant changes were found in palatal depth in either group. However, the NITI

appliances were able to produce significant increases in molar rotation, whereas, the RPE appliances were not. In comparison, RPE appliances produced a greater percentage of skeletal expansion along with significantly greater radiographic evidence of midpalatal sutural separation. Also, in the RPE group, expansion of the maxilla was more predictable with alveolar tipping, palatal width change, and molar tipping explaining 82 % of the increase in intermolar width. In comparison, the NITI group showed much more unexplained variability with none of the variables being significantly related to intermolar width increase. Also age was found not to be significantly related to palatal expansion in either the NITI expansion group or RPE group.

Results of this study suggest that both appliances are capable of expanding the maxilla. In comparison, RPE appliances produce more skeletal expansion and are more predictable in their affect on the maxilla, whereas, NITI expansion appliances are less predictable in their affect on the maxilla but are capable of correcting molar rotations. Neither method of expansion was found to be dependent on the patient's age.

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A COMPARISON OF DENTAL AND SKELETAL CHANGES BETWEEN RAPID PALATAL EXPANSION AND NICKEL TITANIUM PALATAL EXPANSION

By

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A THESIS

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APRROVAL OF EXAMINING COMMITTEE

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